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Prevention Reference Manual: Chemical Specific Volume 3. Control of Accidental Releases of Hydrogen Cyanide (SCAQMD) (South Coast Air Quality Management District)

Radian Corp., Austin, TX

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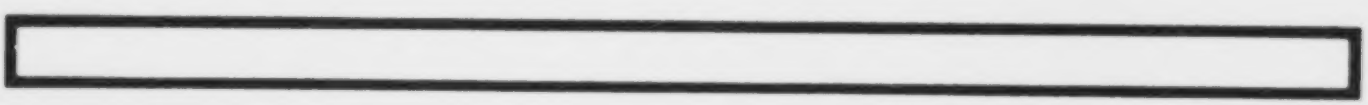

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PREVENTION REFERENCE MANUAL:
CHEMICAL SPECIFIC
VOLUME 3: CONTROL OF ACCIDENTAL RELEASES OF HYDROGEN CYANIDE (SCAQMD)

By:

D.S. Davis
G.B. DeWolf
J.D. Quass
Radian Corporation
Austin, Texas 78766

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EPA Project Officer

T. Kelly Janes
Air and Energy Engineering Research Laboratory
Research Triangle Park, North Carolina 27711

AIR AND ENERGY ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

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16. ABSTRACT The report discusses a strategy (being considered by the South Coast Air Quality Management District--SCAQMD--of Southern California) for reducing the risk of a major accidental air release of toxic chemicals. This strategy, intended to guide both industry and communities, consists of monitoring activities associated with the storage, handling, and use of certain chemicals. The hydrogen cyanide (HCN) manual summarizes technical information that will aid in identifying and controlling release hazards (specific to the SCAQMD) associated with HCN. Because HCN has an IDLH (immediately dangerous to life and health) concentration of 50 ppm, it is an acute toxic hazard. The manual identifies the potential causes of accidental releases that apply to processes using cyanides in the SCAQMD and also describes measures that may be taken to reduce the accidental release risk. Such measures include recommendations on plant design practices; prevention, protection, and mitigation technologies; and operation and maintenance practices. Conceptual cost estimates of examples of these measures are provided.

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Hydrogen Cyanide	Storage	Stationary Sources	07B 15E
Electroplating	Materials Handling	Accidental Releases	13H
Prevention	Maintenance		14G
Accidents			13L
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ABSTRACT

The South Coast Air Quality Management District (SCAQMD) of Southern California has developed a strategy for reducing the risk of a major accidental air release of toxic chemicals. The strategy includes monitoring activities associated with the storage, handling, and use of certain chemicals; providing guidance to industry and communities. This manual summarizes technical information that will help the user identify and control release hazards specific to the SCAQMD associated with hydrogen cyanide.

Hydrogen cyanide has an IDLH (Immediately Dangerous to Life and Health) concentration of 50 ppm, which makes it a substantial acute toxic hazard. Reducing the risk associated with an accidental release of hydrogen cyanide involves identifying some of the potential causes of accidental releases. Examples of potential causes are identified, along with specific measures that may be taken to reduce the accidental release risk. Such measures include recommendations on plant design practices; prevention, protection and mitigation technologies; and operation and maintenance practices. Conceptual cost estimates of possible prevention, protection, and mitigation measures are provided.

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SECTION 1
INTRODUCTION

1.1 BACKGROUND

Recognizing the risk associated with accidental releases of air toxics in southern California, the South Coast Air Quality Management District (SCAQMD), conducted a study in 1985 to determine the presence, quantities, and uses of hazardous chemicals in the SCAQMD, which comprises Los Angeles, Orange, San Bernadino, and Riverside Counties. The SCAQMD study resulted in a report, "South Coast Air Basin Accidental Toxic Air Emissions Study," which outlined an overall strategy for reducing the potential for a major toxic chemical release incident.

The strategy includes monitoring industry activities associated with the storage, handling, and use of certain chemicals; using the best technical information available; and guiding industry and communities in minimizing the potential for accidental releases and the consequences of any release that might occur.

There appear to have been no significant releases of hydrogen cyanide in the SCAQMD. Although major incidents elsewhere involving hydrogen cyanide have not been common, release of hydrogen cyanide at a silver recovery company in Illinois in 1985 caused the death of one employee (1).

1.2 PURPOSE OF THIS MANUAL

This manual compiles technical information on hydrogen cyanide, and specifically on the prevention of accidental releases of hydrogen cyanide. It addresses technological and procedural factors associated with the storage, handling, and processing of cyanides that might result in a release of

hydrogen cyanide in the SCAQMD. Apparently, hydrogen cyanide itself is not used within the SCAQMD; only its salts are used in electroplating operations.

This summary manual is intended to assist persons reviewing and evaluating the potential for releases of hydrogen cyanide. It refers the reader to additional technical sources for more complete information on the topics discussed. Other sources include manufacturers and distributors of cyanides and metal plating equipment and supplies, and technical literature on design, operation, and loss prevention in facilities handling toxic chemicals.

1.3 USES OF CYANIDES

Various cyanides are used in the chemical industry. In most cases, they are used in the form of aqueous salt solutions or as aqueous hydrogen cyanide. The cyanide ion can form aqueous complexes with most metals, which makes it an excellent carrier of metals in electrolytic processes.

Limited survey data indicate that the primary use of cyanides appears to be in the electroplating industry (2), where they are used in two areas of the process: in plating solutions for certain metals, and in cleaning solutions used to prepare metal surfaces for plating. In a properly functioning plating operation, the cyanide is present only in the salt form and not as hydrogen cyanide.

Cyanides are stored in drums as a dry salt. The most common salt is sodium cyanide. It appears that hydrogen cyanide is not stored or used as a gas or in aqueous solution in the plating industry in the SCAQMD.

1.4 ORGANIZATION OF THE MANUAL

The remainder of this manual presents technical information on specific hazards and categories of hazards and their control as they relate to hydrogen

cyanide. The treatment here is not exhaustive; there may be other hazards not covered.

Section 2 discusses physical, chemical, and toxicological properties of hydrogen cyanide. Section 3 describes the types of facilities that use hydrogen cyanide in the SCAQMD and process hazards associated with these facilities. Hazard prevention and control are discussed in Section 4. Costs of example storage and process facilities reflecting different levels of control through alternative systems are also presented in Section 4. The examples are for illustration only and do not necessarily represent a satisfactory alternative control option in all cases. Section 5 presents a reference list. Appendix A is a glossary of key technical terms that might not be familiar to all users of the manual, and Appendix B presents selected conversion factors between metric (SI) and English measurement units.

SECTION 2
CHEMICAL CHARACTERISTICS

This section describes the physical, chemical, and toxicological properties of hydrogen cyanide, sodium cyanide, and potassium cyanide, which are the most common cyanide salts used in the plating industry; their properties are similar to those of other cyanide salts. Hydrogen cyanide, which is the volatile form, is the compound of concern when considering the possibility of an accidental air release.

2.1 PHYSICAL PROPERTIES

Anhydrous hydrogen cyanide is a colorless to pale yellow liquid with a mild odor similar to bitter almonds. The liquid boils at 78.3°F and 760 mm Hg and forms a colorless, flammable, toxic gas. Table 2-1 lists the physical properties of anhydrous hydrogen cyanide.

Anhydrous hydrogen cyanide is not used directly in electroplating processes in the SCAQMD. Cyanide is handled in the salt form as a dry powder or as an aqueous solution. Anhydrous sodium cyanide, probably the most common form of cyanide used in the SCAQMD, is a white solid available in briquette, granular or powder form. The solids are nonflammable and highly toxic. Table 2-2 shows the physical properties of anhydrous sodium cyanide. The solubility of sodium cyanide in water as a function of temperature is shown in Figure 2-1. The density of aqueous sodium cyanide solutions as a function of concentration is shown in Figure 2-2.

Potassium cyanide is another common form of cyanide used in the SCAQMD. The physical properties of potassium cyanide are similar to those of sodium cyanide; these are listed in Table 2-3.

TABLE 2-1. PHYSICAL PROPERTIES OF HYDROGEN CYANIDE

		Reference
CAS Registry Number	74-90-8	
Chemical Formula	HCN	
Molecular Weight	27.03	
Normal Boiling Point	78.3 °F @ 1 atm	3
Melting Point	8.17 °F	4
Liquid Specific Gravity (H_2O = 1)	0.6884 @ 68 °F	3
Vapor Specific Gravity (air = 1)	0.947 @ 88 °F	3
Vapor Pressure	0.348 atm @ 32 °F	3
Vapor Pressure Equation		5

$$\log Pv = A - \frac{B}{T+C}$$

where: Pv = vapor pressure, mmHg
T = temperature, °C
A = 7.5282, a constant
B = 1329.5, a constant
C = 260.4, a constant

Liquid Viscosity	0.2014 centipoise @ 68 °F	3
Solubility in Water	Complete	4
Specific Heat at Constant Pressure	16.94 cal/(mol-°C) @ 62.4 °F	4
Latent Heat of Vaporization	10,834 Btu/lbmole @ 77 °F	4

(Continued)

TABLE 2-1 (Continued)

		Reference
Liquid Surface Tension	17.2 dyn/cm @ 77 °F	4
Heat of Combustion	287,000 Btu/lbmole	4
Autoignition Temperature	1000 °F	4
Explosive Range, Volume % in Air @ 100 kPa and 20°C	min. 6 max. 41	4
Flash Point, TCC (ASTM D-56)	0 °F	4

Additional properties useful in determining other properties from physical property correlations:

Critical Temperature	362.3 °F	4
Critical Pressure	53.2 atm	4
Critical Density	12.2 lb/ft^3	4

TABLE 2-2. PHYSICAL PROPERTIES OF ANHYDROUS SODIUM CYANIDE

CAS Registry Number	00143-33-9
Molecular Weight	49.01
Melting Point	1044 °F
Specific Gravity (H_2O = 1)	1.6 @ 77 °F
Heat of Formation	-78 Btu/lb @ 77 °F
Heat of Fusion	77 Btu/lb
Heat of Vaporization	1309 Btu/lb
Vapor Pressure, mmHg	0.76 mmHg @ 1472 °F 89.8 mmHg @ 2192 °F 314.0 mmHg @ 4496 °F
Solubility in Water	58.3 g NaCN/100g water @ 68 °F
pH in Solution	11.3 to 11.7 (5-25% solutions with no pH adjustment)

Source: Reference 6,7

TABLE 2-3. PHYSICAL PROPERTIES OF ANHYDROUS POTASSIUM CYANIDE[a]

CAS Registry Number	00151-50-8
Molecular Weight	65.12
Melting Point	1174 °F
Boiling Point	Not available
Specific Gravity	1.52
Vapor Pressure	Negligible at 68 °F
Solubility in Water	41.7% @ 77 °F
pH in Solution	10.8 (saturated aqueous solution)

[a]Only limited physical property data for potassium cyanide were available in the sources used for this study.

Source: Reference 8

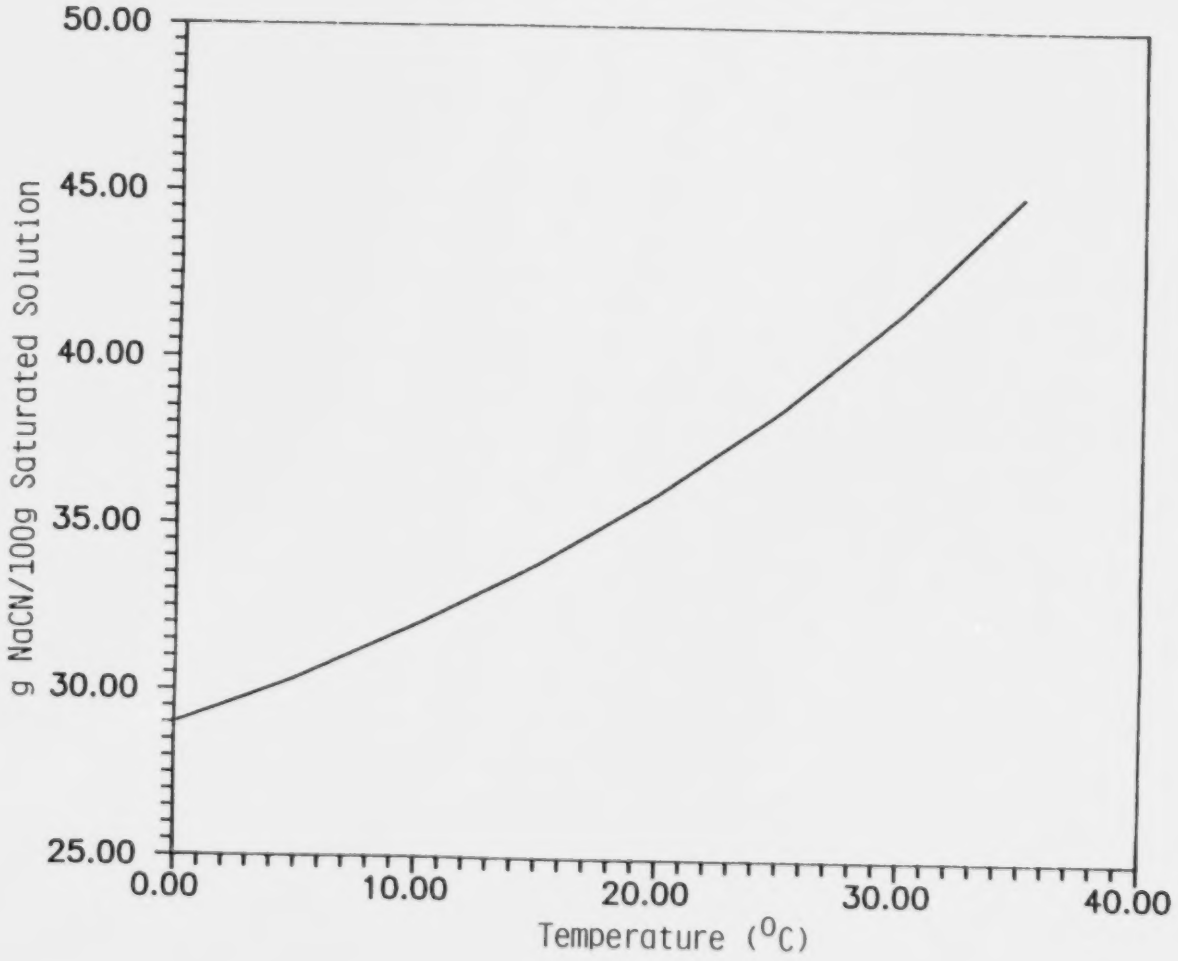

Figure 2-1. Solubility of sodium cyanide in water.

Source: Adapted from Reference 2

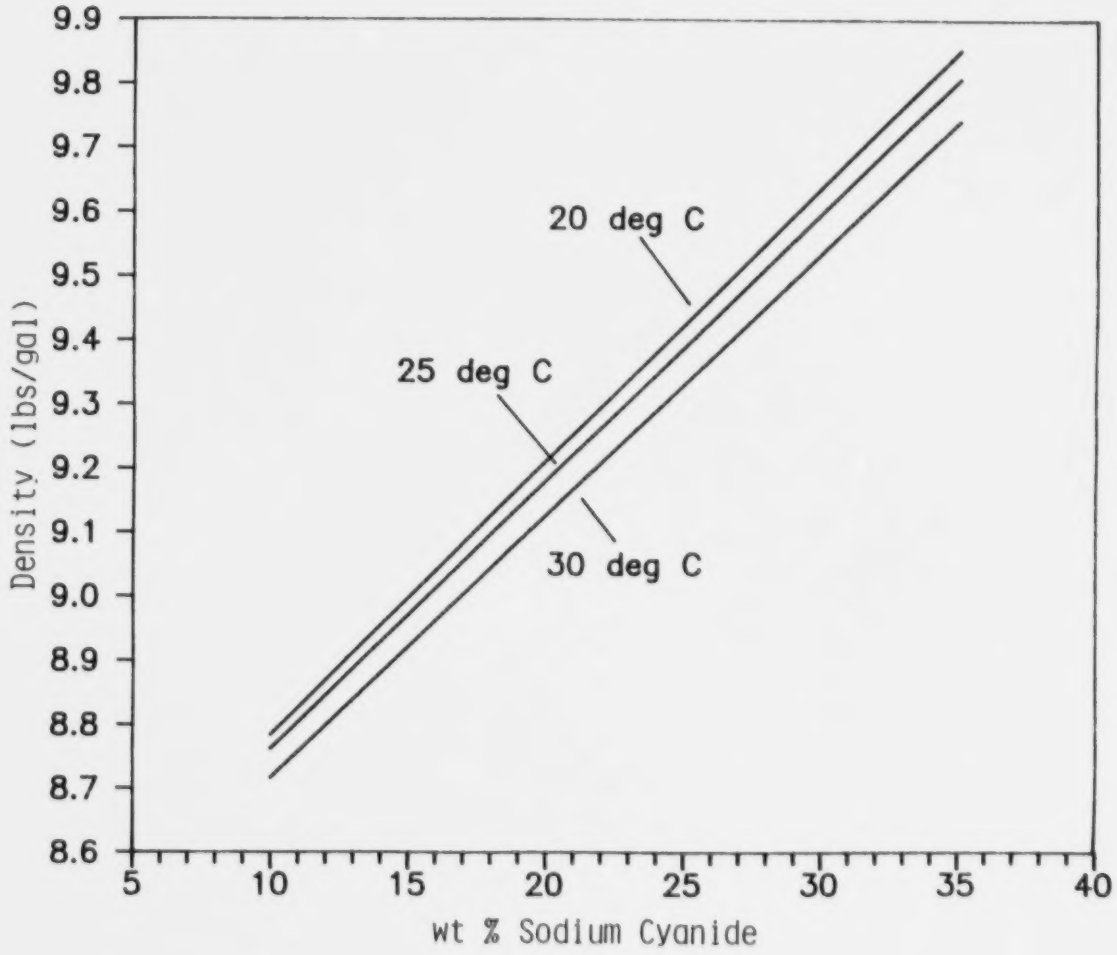

Figure 2-2. Densities of sodium cyanide solutions.

Source: Adapted from Reference 6

2.2 CHEMICAL PROPERTIES AND REACTIVITY

The chemical properties of sodium and potassium cyanide that contribute to the formation of hydrogen cyanide and therefore to the potential for an accidental release of hydrogen cyanide are (6,7,8):

- Hydrogen cyanide can be formed when the pH of aqueous solutions of sodium or potassium cyanide is lowered. Figure 2-3 illustrates the effect of pH on the formation of hydrogen cyanide in a solution of sodium cyanide*. Some of the HCN formed will evaporate. Rapid changes in pH could result in rapid formation and gaseous release of HCN. This appears to be the most severe chemical hazard associated with the use of hydrogen cyanide in the plating industry.

- Wetting anhydrous cyanide salts can liberate hydrogen cyanide (in small amounts). Additionally, very low levels of hydrogen cyanide are present just above the surface of cyanide salt solutions. A hazardous situation could result if a major spill of a cyanide solution occurred or if stored cyanide salts were wetted.

- Cyanide decomposes slowly in water to form ammonia and formate ions. At 68°F, a 35% sodium cyanide solution will decompose at a rate of 0.04% of the NaCN in solution per 24-hour period (6). The rate of decomposition increases with increasing temperature. At 104°F a 35% sodium cyanide solution will

---

*In an actual cyanide plating solution, the cyanide is complexed with the metal being plated. Additionally, these solutions have several ionic species that will influence the pH vs. HCN curve. Figure 2-3 is illustrative, but not representative of a plating solution. Additional discussion on pH versus cyanide concentration will be presented in Section 6.

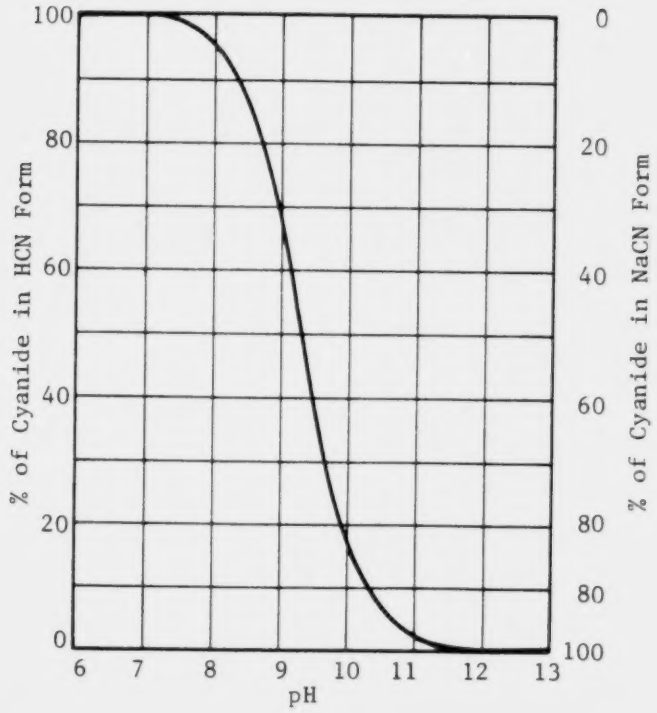

Figure 2-3. Effect of pH on the formation of hydrogen cyanide in a solution of sodium cyanide.

Source: Adapted from Reference 6.

decompose at a rate of about 0.3% of the NaCN in solution per 24-hour period (3). Ammonia formation can cause a sealed container of cyanide solution to develop a significant pressure.

2.3 TOXICOLOGICAL AND HEALTH EFFECTS

Hydrogen cyanide, sodium cyanide and potassium cyanide are all highly toxic by ingestion, inhalation and skin adsorption. The cyanides are true noncumulative protoplasmic poisons (i.e., they can be detoxified readily). They combine with those enzymes at the blood/tissue interfaces that regulate oxygen transfer to the cellular tissues. Unless the cyanide is removed, death results through asphyxia. The warning signs of cyanide poisoning include: dizziness, numbness, headache, rapid pulse, nausea, reddened skin, and bloodshot eyes. More prolonged exposure causes vomiting and labored breathing, followed by unconsciousness, cessation of breathing, rapid weak heart beat, and death. Severe exposure (by inhalation) can cause immediate unconsciousness; this rapid knockdown power without any irritation or detectable odor to some people makes hydrogen cyanide more dangerous than other materials of comparable toxicity (e.g., hydrogen sulfide). Table 2-4 summarizes some of the relevant exposure limits for hydrogen cyanide. Table 2-5 summarizes the predicted human health effects of exposure to various concentrations of hydrogen cyanide.

TABLE 2-4. EXPOSURE LIMITS FOR HYDROGEN CYANIDE

Exposure Limit	Concentration (ppm)	Description	Reference
IDLH[a]	50	The concentration defined as posing an immediate danger to life and health (i.e., causes toxic effects for a 30-minute exposure).	9
PEL	10	A time-weighted 8-hour exposure, to this concentration, as set by the Occupational Safety and Health Administration (OSHA), should result in no adverse effects for the average worker.	10
LCLo	178	This concentration is the lowest published lethal concentration for a human over a 10-minute exposure.	10

[a]Note that although the focus of this report is on hydrogen cyanide, sodium cyanide and potassium cyanide solutions can be lethal by ingestion or absorption. Potassium cyanide lethal dose in humans is less than 5 mg/kg or less than a taste (0.01 oz) for a 150 pound person (10).

TABLE 2-5. PREDICTED HUMAN HEALTH EFFECTS OF EXPOSURE TO VARIOUS CONCENTRATIONS OF HYDROGEN CYANIDE

ppm	Predicted Effect
2-5	Odor threshold.
20	Causes slight symptoms including headache and dizziness after several hours.
50	Causes disturbances within an hour.
100	Dangerous for exposures of 30-60 min.
300	Rapidly fatal unless prompt, effective first aid is administered.

Source: Reference 3

SECTION 3
FACILITY DESCRIPTIONS AND PROCESS HAZARDS

This section briefly describes the uses of cyanide in the SCAQMD and highlights major process hazards related to accidental releases. Preventive measures associated with these hazards are discussed in Section 4.

3.1 PROCESSING

According to the survey data, the primary use for cyanide in the SCAQMD appears to be in the metal plating industry. Cyanide salts serve as complexing agents in the electrolytic cleaning and stripping of metal surfaces before plating, and in the electroplating process itself. These processes are discussed below. It is important to note that the plating industry has been moving away from the use of cyanide. At one time, most plating processes, such as zinc plating, required cyanide plating solutions. Now, however, substitutes are available for many metals in certain applications.

Plating processes are usually carried out in a row of open baths, (approximately 5-15 baths), all contained in a ventilated building. Sometimes fume hoods are used over these baths, but often the building ventilation system is used to ventilate the process area. In many respects, a plating process is stagnant. Small quantities of liquid cling to the parts as they are transferred between baths, thereby contaminating each bath. However, this "flow" of liquid between baths is very small. Probably the only other flow of material in a plating process is through individual bath filtering loops. The only control system is likely to be temperature control on some of the baths. Transfers, monitoring and composition adjustments are typically done by hand.

3.1.1 Electrolytic Cleaning

A metal surface must undergo a number of preparation steps before the actual plating operation. Adequate adhesion of the plate will depend on the elimination of surface contaminants and on activation of the surface over the entire area to be plated.

Some typical surface preparation operations include (3,11,12): a) acidic pickling to remove scale; b) solvent precleaning to remove soil; c) alkaline cleaning to remove soil and grease; d) electrocleaning to remove the last traces of solids and other contaminants that are especially adherent; e) acid treatment and surface conditioning to remove light oxide films formed during previous cleaning processes and to microetch the surface; f) electrolytic (anodic) cleaning to remove residue formed during acid pickling and to oxidize scale. A flow chart showing the steps required to prepare steel for electroplating is shown in Figure 3-1.

Electrolytic cleaning (electrocleaning) is the only step in the surface preparation process where cyanide is sometimes employed.* Two types of electrocleaning are used; anodic and cathodic.

Anodic electrocleaning is most commonly used on ferrous metals. Figure 3-2 illustrates a workpiece being cleaned anodically and gives the accompanying reaction. Because the workpiece is actually the anode (positive), free electrons are discharged by the hydroxyl ions to the metal, resulting in the liberation of gaseous oxygen. The oxygen bubbles liberated at the workpiece create a scrubbing action, which actually loosens dirt particles from the

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*Cyanide is employed in the stripping process for removing old metal plate. This process is so similar to the plating process that it is discussed in Section 3.1.2 on Electrolytic Plating.

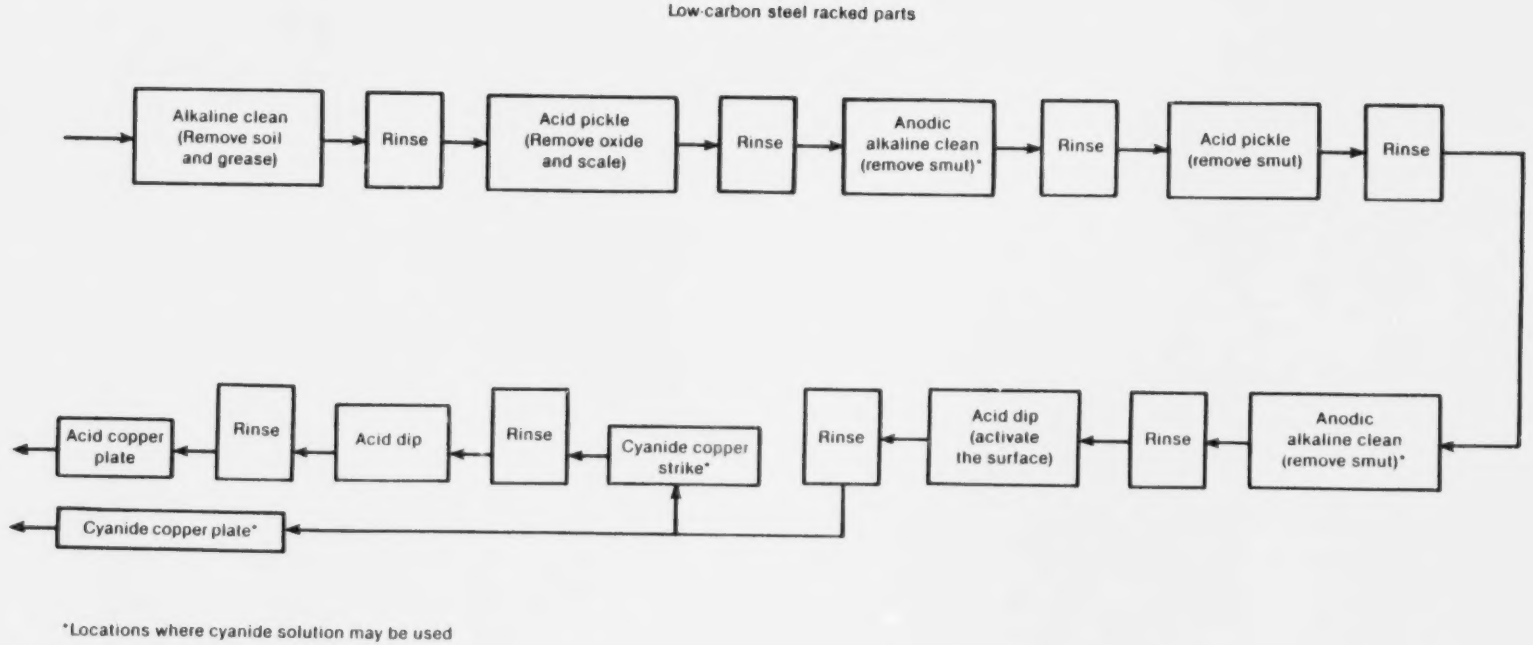

Figure 3-1. Flow chart of process for preparing steels for electroplating.

Source: Adapted from Reference 11

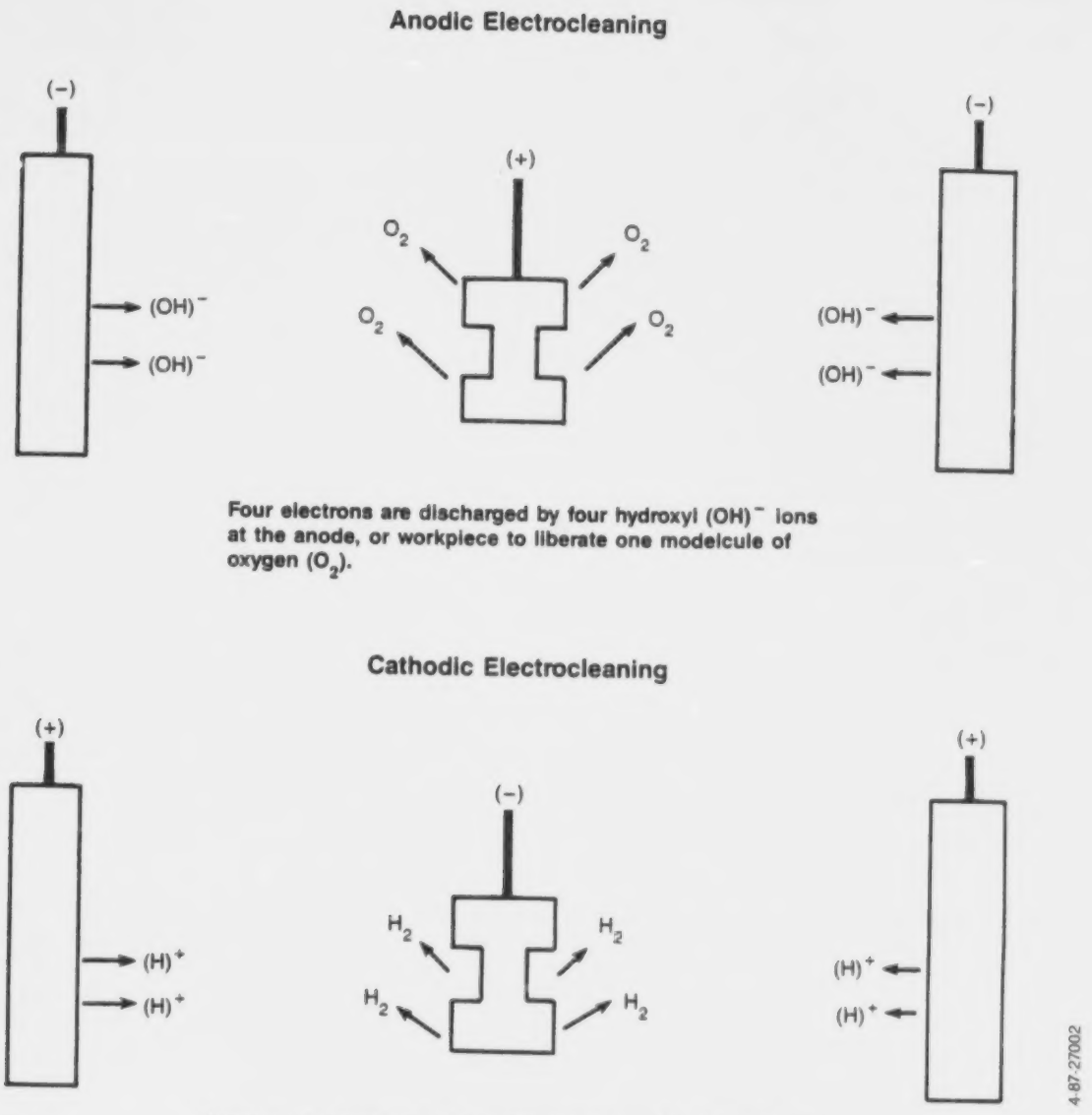

Figure 3-2. Reactions in electrocleaning processes.

Source: Adapted from Reference 11.

workpiece. These bubbles rise to the top of the cleaner, increasing solution agitation and continually bringing fresh cleaning solution to the workpiece.

Cathodic electrocleaning employs a negative charge on the part undergoing surface preparation. Insoluble steel or nickel-plated steel anodes are used. The cleaning action obtained is somewhat better than that of anodic cleaning because hydrogen gas is evolved at the cathode (workpiece), and at a given current density, twice the volume of hydrogen is liberated at the cathode than oxygen at the anode. The added mechanical scrubbing action and solution agitation, coupled with the fact that the negatively charged workpiece repels negatively charged particles of soil, are the major advantages of cathodic cleaning. Figure 3-2 illustrates cathodic electrocleaning. The electrons are supplied to the cathode where they combine with positive hydrogen ions to liberate hydrogen gas.

Both anodic and cathodic cleaning have specific advantages for certain applications (11,12). In both anodic and cathodic electrocleaning, cyanide can be used as a carrier of ionic species. All electrolytic cleaning processes are carried out at a high pH, and all of the cyanide will be tied up as a metallic complex or as the cyanide salt. Hydrogen cyanide will not be liberated unless the pH is lowered. A significant hazard could result if the pH were lowered in an electrolytic cleaning solution employing cyanide. An operator, for instance, could accidentally add enough acid to lower the pH of the solution.

The performance of these cleaning solutions is not as pH dependent as is the performance of a plating solution. For this reason, the pH of these solutions tends not to require adjustment as often as does the pH of a plating bath, and the risk of operator error is probably low.

3.1.2 Electrolytic Plating

Electrolytic plating (electroplating) is another step in the plating process that sometimes requires the use of cyanide. For almost every commonly plated metal, a cyanide-based or a non-cyanide-based process may be used. For some metals, the non-cyanide process has very limited applicability, and in these situations, the cyanide-based process is preferred. Examples of common metals that often require cyanide-based plating processes include copper, cadmium, silver, and brass. For some metals these are non-cyanide processes available that are so broad in their applicability that they may be substitutes for the cyanide-based process. Examples of this include zinc, chromium, and nickel.

In electroplating, the material being treated (the substrate) is used as the cathode. The metal to be plated onto the substrate is used as the anode. Both electrodes are submerged in an aqueous bath. The composition of the aqueous bath is complex and will be different for each metal and for each substrate. Figure 3-3 illustrates a typical plating tank. The metal anodes are hung into the tank from the positive bus bar, usually along the two sides. The work to be plated is hung on racks, wire baskets, or barrels suspended along the center of the tank and attached to the negative cathode bar. The solution is usually agitated. Example methods of agitation include automatic cathode-rod agitation or air sparging. The temperature of the plating solution is controlled by heating and cooling systems.

Every plating solution contains ingredients to perform at least one, and usually several, of the following functions (3,11,12): (1) provide a source of ions for the metal(s) to be deposited; (2) form complexes with ions of the depositing metal; (3) provide conductivity; (4) stabilize the solution against hydrolysis or other forms of decomposition; (5) buffer the pH of the solution; (6) regulate the physical form of the deposit; (7) aid in anode corrosion; and (8) modify other properties peculiar to the solution involved.

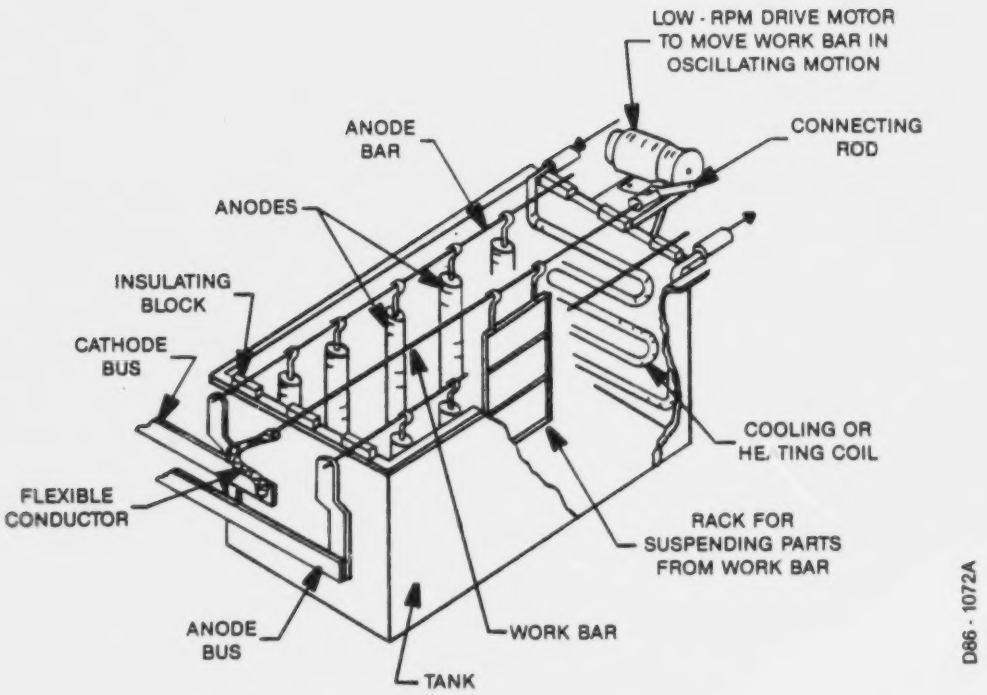

Figure 3-3. Cut-away view of a typical plating tank.

Source: Adapted from Reference 11.

Cyanide is used in plating solutions because it performs functions (1), (2), (3), and (7). The actual function of cyanide in the plating process will be illustrated in the discussions on plating of specific metals.

Where cyanides are used, it is important to distinguish between total cyanide and free cyanide. Cyanide will be present in two forms in solution; as a complex with the metal to be plated and as the free anion (CN^-). The total cyanide is the sum of both. The free cyanide is the cyanide present in the anion form. The metal complexes of cyanide are usually quite stable and less resistant to the formation of HCN when the pH is lowered than is the cyanide anion.

A properly maintained plating bath may last for more than 20 years before needing to be replaced (11,12). Maintenance of the bath includes regularly filtering impurities and readjusting the solution composition, which are required because dirt, grease and solutions from other baths are brought in clinging to the surface of the materials to be plated. Additionally, CO_2 in agitation air will react with alkaline species, and cyanide ions will slowly decompose to form CO_2 and ammonia.

The plating bath compositions for several commonly plated metals that use cyanide are discussed below. As will be discussed later, the individual bath compositions influence how sensitive a bath is to cyanide evolution with a decrease in pH.

Copper --

Both alkaline cyanide processes and acidic non-cyanide plating processes are available for copper.

Possibly the most common varieties of copper-cyanide plating baths are the dilute cyanide baths. The dilute baths are common because in most of the non-cyanide copper plating processes, and in several plating processes for other metals, a thin layer of copper must be applied to the substrate as a

surface preparation via a dilute cyanide process before the second metal can be applied.

One variation of a dilute cyanide bath is the Rochelle bath, a dilute bath with potassium sodium tartrate (referred to as the Rochelle salt) added. The Rochelle salt increases the rate and total thickness of copper that may be applied. Table 3-1 shows the typical composition and operating conditions for a Rochelle cyanide bath (11).

Higher efficiency cyanide baths are used where a thicker layer of copper is required. A typical high efficiency bath composition is shown in Table 3-2 (12).

Several alternatives to copper-cyanide-based baths are available; all of the alternatives have limitations. As mentioned above, in most cases, a dilute copper-cyanide plating step must precede the alternative, which makes it difficult to eliminate cyanide altogether. The copper pyrophosphate bath is an alkaline alternative to a high efficiency copper cyanide bath. This bath has characteristics comparable to the high-efficiency cyanide bath. For pyrophosphate plating on steel, zinc die castings, magnesium or aluminum, a preliminary strike using a dilute cyanide bath should be used. Several acidic plating processes are available. When these processes are used to plate onto steel or zinc-alloy, they must be preceded by a copper-cyanide or nickel-cyanide strike.

Cadmium --

Most cadmium plating is carried out in alkaline cyanide baths prepared by dissolving cadmium oxide (CdO) in a sodium cyanide solution. The characteristics of the bath are determined by the ratio of the total sodium cyanide to cadmium metal content. Table 3-3 lists the composition of various cadmium-cyanide solutions (12).

TABLE 3-1. COMPOSITION AND OPERATING CONDITIONS FOR A TYPICAL DILUTE COPPER-CYANIDE PLATING BATH

	Potassium	Sodium
Copper cyanide	1.87 lb/ft^3	1.87 lb/ft^3
Total potassium cyanide	3.65 lb/ft^3	--
Total sodium cyanide	--	3.00 lb/ft^3
Potassium hydroxide	0.23-0.47 lb/ft^3	--
Sodium hydroxide	--	0.23-0.47 lb/ft^3
Potassium carbonate	0.94 lb/ft^3	--
Sodium carbonate	--	0.94 lb/ft^3
Rochelle salt	1.87 lb/ft^3	0.19 lb/ft^3
Temperature	75-140°F	
Recommended agitation	None or mechanical	

Source: Adapted from Reference 12.

TABLE 3-2. COMPOSITION AND OPERATING CONDITIONS FOR A TYPICAL HIGH EFFICIENCY COPPER-CYANIDE PLATING BATH

	Potassium	Sodium
Copper cyanide	3.75 lb/ft^3	4.68 lb/ft^3
Total potassium cyanide	6.37 lb/ft^3	--
Total sodium cyanide	--	6.09 lb/ft^3
Potassium carbonate	0.94 lb/ft^3	--
Sodium carbonate	--	0.94 lb/ft^3
Potassium hydroxide	0.94 lb/ft^3	--
Sodium hydroxide	--	0.94 lb/ft^3
Rochelle salt	2.81 lb/ft^3	2.81 lb/ft^3
Temperature	140-160°F	
Recommended agitation	Mechanical, solution or air	

Source: Adapted from Reference 12.

TABLE 3-3. VARIOUS COMPOSITIONS FOR TYPICAL CADMIUM-CYANIDE PLATING BATHS

Total $NaCN^-$ to-Cd Ratio	Cd	CdO	NaCN	NaOH	Na_2CO_3
4.0	2.6	3.0	10.4	1.9	4-10
4.1	2.6	3.0	10.7	8.0	4-6
4.5	4.8	5.5	21.6	3.4	4-6
5.0	2.7	3.0	13.5	1.9	4-8
7.2	2.6	3.0	18.2	1.9	4-6

Source: Adapted from Reference 12

Non-cyanide plating baths are available. All of the non-cyanide baths have less ability to plate evenly over the entire plating surface (referred to as "throwing power") than the cyanide based baths and cannot be used as universal substitutes for cadmium cyanide.

Silver --

Virtually all silver plating is carried out in alkaline cyanide baths. Table 3-4 shows the typical composition and operating conditions for a silver-cyanide plating bath (12).

TABLE 3-4. COMPOSITION AND OPERATING CONDITIONS FOR A TYPICAL SILVER-CYANIDE PLATING BATH

Silver, as $KAg(CN)_2$	0.31-2.50 lb/ft3F
Potassium cyanide (free)	0.75-7.49 lb/ft^3
Potassium carbonate (min.)	0.94 lb/ft^3
Temperature	70-85°F

Source: Adapted from Reference 12

Almost every known silver compound has been investigated, with very little success, as an electrolyte base for replacing cyanide in the silver plating process. A few proprietary non-cyanide formulations have been developed but all have inferior tarnish resistance and are more expensive to operate.

Brass --

Brass plating is accomplished exclusively in cyanide-based plating baths. Table 3-5 shows a typical brass plating solution composition and operating conditions (12).

TABLE 3-5. COMPOSITION AND OPERATING CONDITIONS FOR A TYPICAL BRASS-CYANIDE PLATING BATH

Copper cyanide	2.00 lb/ft^3
Zinc cyanide	0.62 lb/ft^3
Sodium cyanide	3.12 lb/ft^3
Sodium carbonate (soda ash)	0.47 lb/ft^3
Sodium bicarbonate	0.62 lb/ft^3
Ammonia	1 to 2 quarts per 100 gal
pH	10.0 to 10.2
Operating Temperature	75 to 95°F

Source: Adapted from Reference 12.

Stripping --

Occasionally, old plate must be removed from a surface before new plate can be applied. The old plate must be removed by electrolytic stripping. This process is analogous to the plating process except it runs in reverse. Cyanide solutions are frequently used in stripping operations.

3.2 STORAGE AND HANDLING

As a raw material in the plating industry, cyanide is stored and handled as a dry salt. The dry cyanide salt (powder or granules) is stored in drums. Solutions of the cyanide salt are usually made up by manually sprinkling the material into the agitated bath, or by mixing a bucket-size quantity of salt slurry and adding it to the bath.

3.3 POTENTIAL CAUSES OF RELEASES

Although cyanide salts are toxic, cyanide solutions can be used safely in the plating industry. The salts have very low vapor pressures in solution or as solids. From the perspective of an accidental release, hydrogen cyanide (HCN) is the hazardous cyanide form.

Small amounts of HCN will be present whenever a cyanide salt or salt solution is used. Large amounts of HCN could be generated if acid were added to a cyanide salt solution. An accidental release of cyanide would be any event that leads to the release of hazardous quantities or concentrations of HCN.

The potential for a release of HCN from a plating solution on the addition of acid is shown in Figures 3-4 thru 3-7. These figures were developed using Radian's species distribution computer model for aqueous chemical systems. The equilibrium partial pressure of HCN in the vapor phase above a plating bath has been plotted as a function of pH, and as a function of concentrated hydrochloric acid (33 percent HCl) addition. Figure 3-4 shows this relationship for a simple aqueous solution of sodium cyanide (50 g NaCN/liter water). Figures 3-5 thru 3-7 show this relationship for some of the plating bath solutions discussed in Section 3.1.2.

Figure 3-5 illustrates the effect of adding acid to a high efficiency copper plating bath. On the addition of about 0.31 gallons of concentrated,

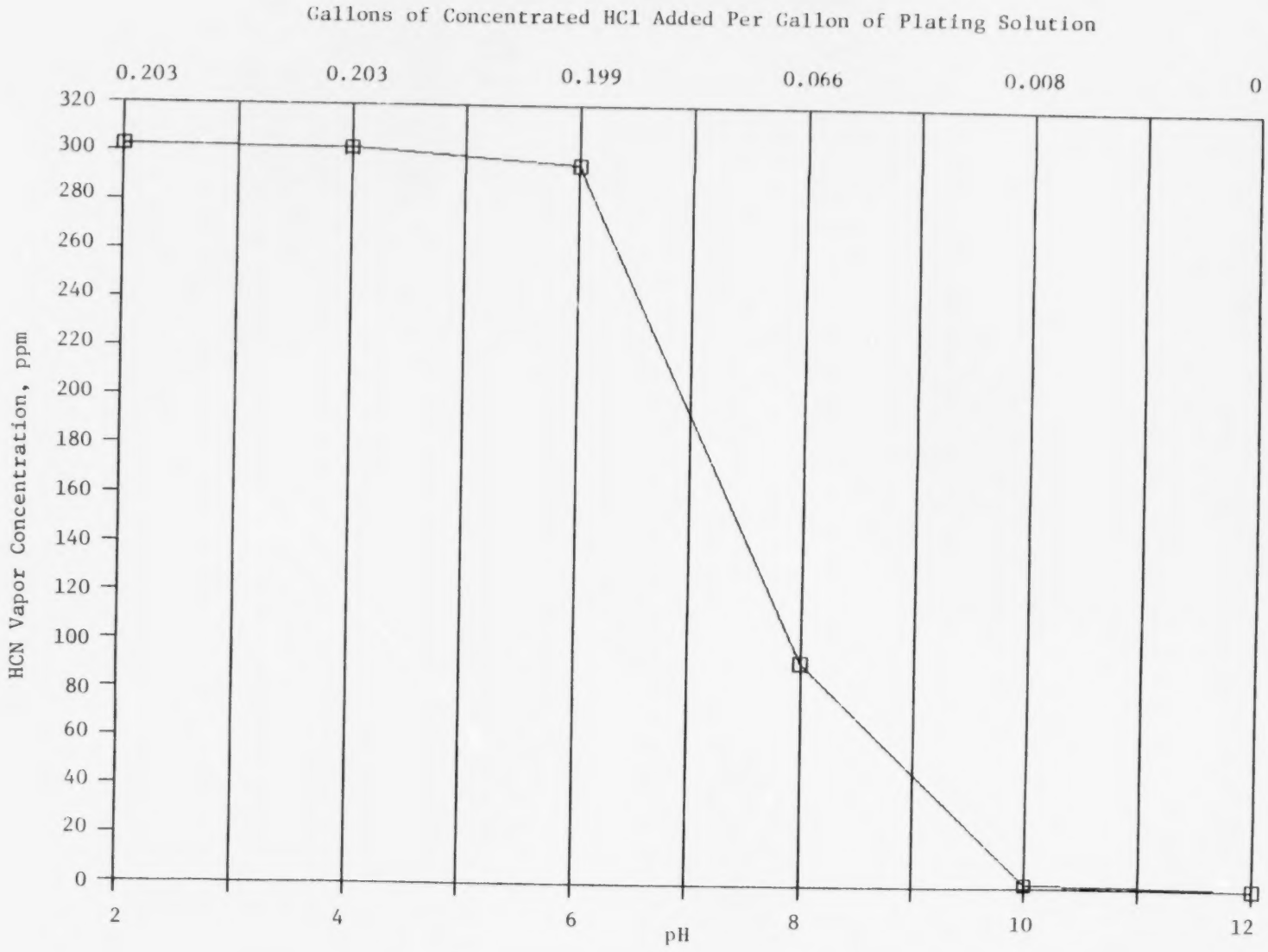

Figure 3-4. HCN vapor concentration vs. pH for 50 g/l NaCN solution.

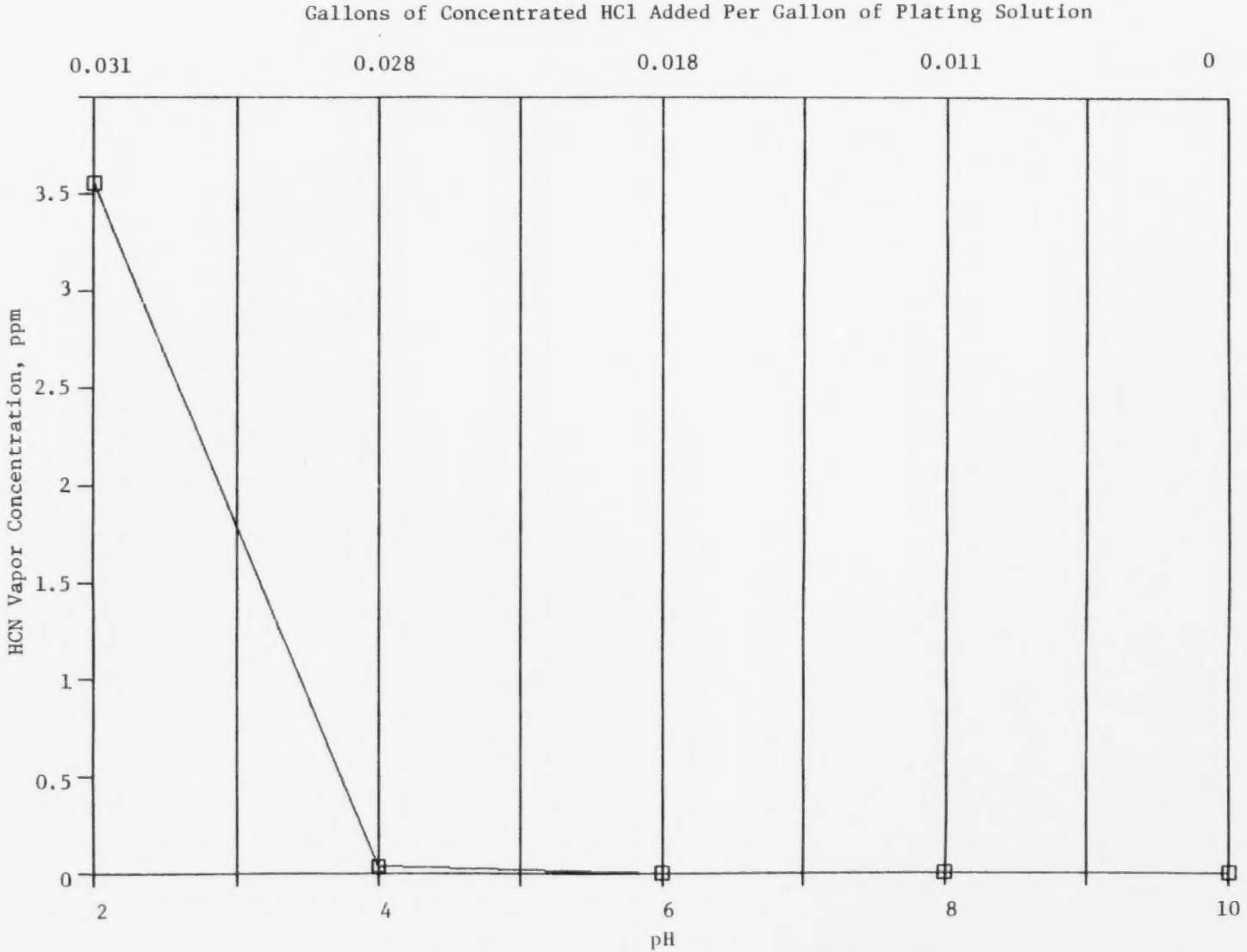

Figure 3-5. HCN vapor concentration vs. pH for high efficiency copper plating solution.

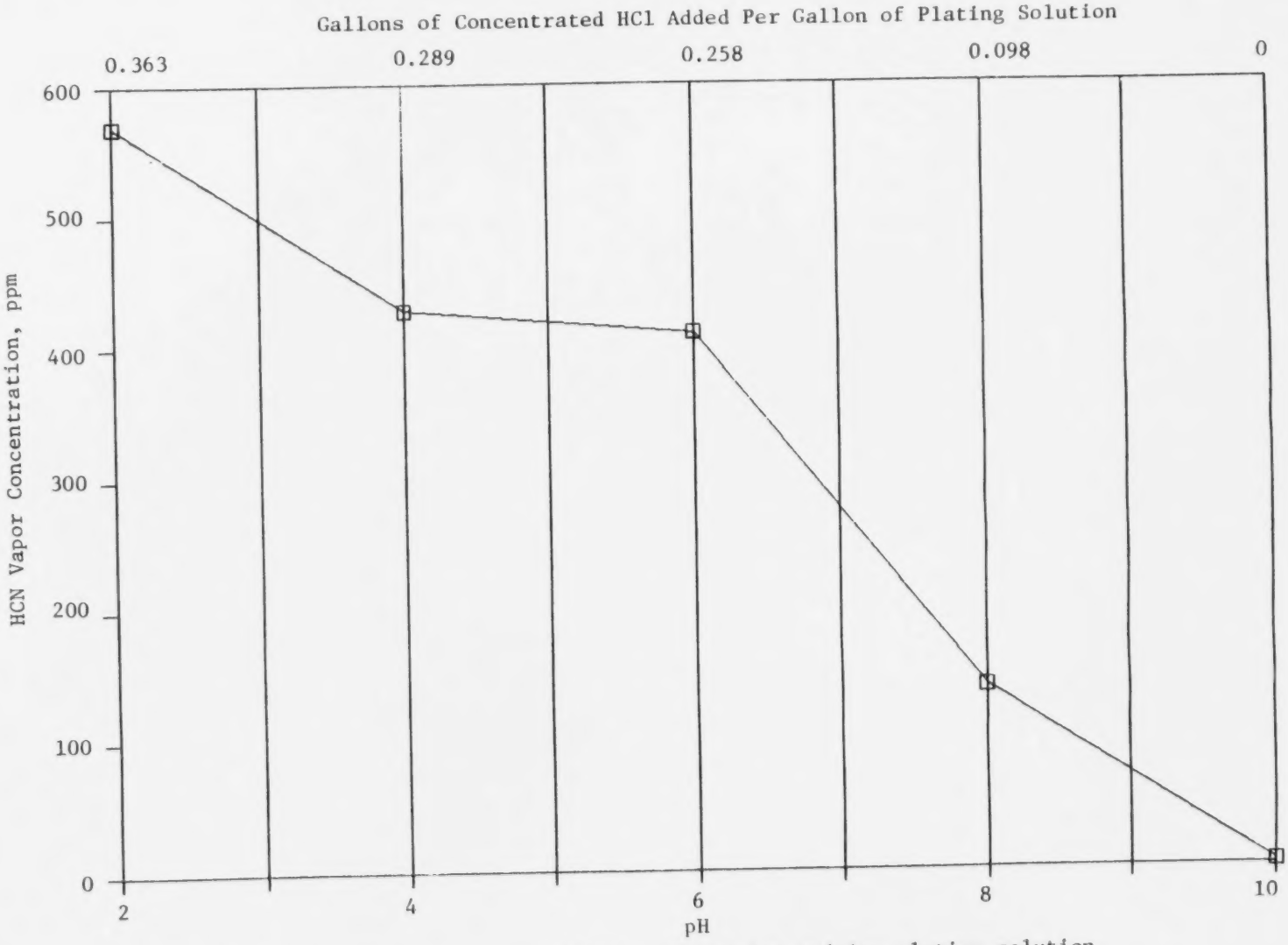

Figure 3-6. HCN vapor concentration vs. pH for cadmium plating solution.

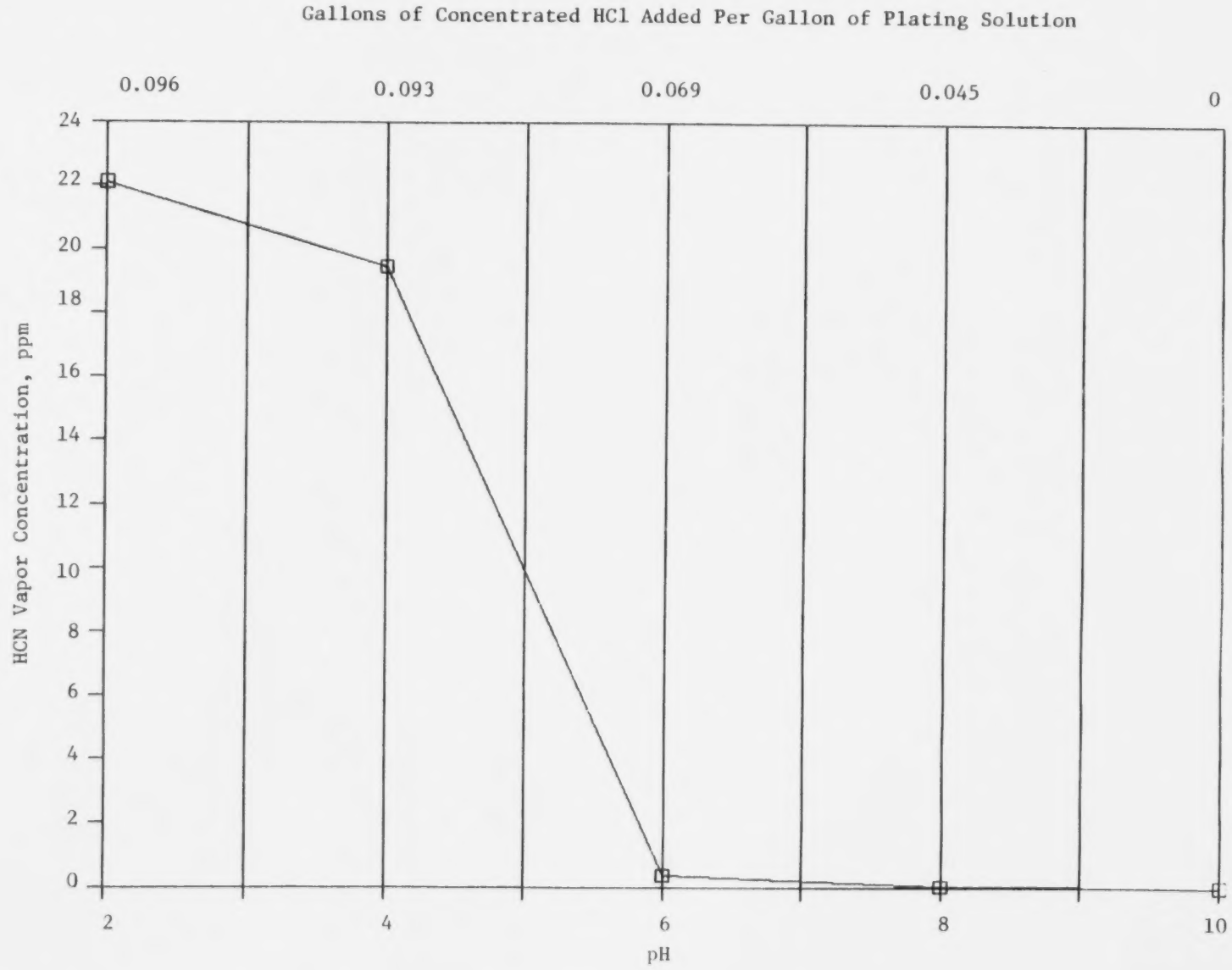

Figure 3-7. HCN vapor concentration vs. pH for brass plating solution.

33 percent HCl per gallon of plating solution, the pH of this bath would be about 2 and the partial pressure of HCN would be about 3.6 ppm. The reason for this low partial pressure is that the cyanide-copper complex is very stable and will keep most of the cyanide in solution even at a very low pH.

Brass contains a large amount of copper, and is also resistant to HCN formation at low pH levels, as illustrated in Figure 3-7. The silver plating solution was not modeled but it would have a pH-to-HCN partial pressure relationship similar to copper and brass.

The cadmium-cyanide complex is weak and the cadmium cyanide plating bath resembles a sodium cyanide solution when acid is added. This is illustrated in Figure 3-6. From this figure it can be seen that the pH of the cadmium solution need only decrease to about 8 before hazardous levels of HCN will be evolved. However, a fairly significant quantity of acid must be added to the solution to reach such a pH. For a 1000 gallon plating bath to reach a pH of 8, approximately two 55 gallon drums of concentrated HCl would need to be accidentally added.

These figures illustrate that an accidental release of HCN from a cyanide based plating bath would require a substantial addition of acid. This fact will be reflected in the remaining discussion.

Problems leading to accidental releases may be broadly classified as caused by process, equipment, or operational failures. Causes discussed below are intended to be illustrative, not exhaustive. A more detailed discussion of possible causes of accidental releases is planned for other portions of the prevention reference manual series.

3.3.1 Process Causes

Process causes involve the fundamentals of process chemistry, control and general operation. Very little automatic process control is typically used in

a plating operation. The various solution compositions within a process are almost always monitored and adjusted manually. Thus, errors in adjustment that might lead to an HCN release would be caused by operator error.

3.3.2 Equipment Causes

Equipment causes of accidental releases would be the result of hardware failure. Some possible causes include:

- Failure of a bath resulting in a spill of cyanide-containing solution. Such a spill would probably have to flow off site before the vapor concentration of HCN would be high enough to affect the community. Such a failure could be caused by excessive stress, external loadings or corrosion.

- A spill similar to that described above could be caused by a pipe or pump failure. Such failures could be due to excessive stress, external loading, erosion or corrosion.

- A fire could result in the accidental release of cyanide. Cyanide salts are not flammable; however, their containers could be damaged by fire. Destruction of containers in storage combined with water from a sprinkler system could result in sodium cyanide runoff. Sprinkler water could also result in tank overflow with mixing of acid baths with cyanide baths. A fire that destroyed the baths themselves or collapsed the surrounding building could result in the mixing of acids with cyanides.

3.3.3 Operational Causes

Operational causes of accidental releases are a result of incorrect procedures or human errors (i.e., not following correct procedures). These causes include:

- Overfill of baths resulting in the mixture of acidic materials with cyanide solutions.

- Incorrect addition of acidic raw materials to a cyanide bath.

- Incorrect transfer of liquid from an acid bath into a cyanide bath or from a cyanide bath into an acid bath.

- Use of a CO_2 fire extinguisher on a fire where cyanide salt or solution is present would provide a source of acid that could result in an accidental release of HCN. However, CO_2 is a weak acid; it may be difficult to expose a cyanide salt or solution to sufficient quantities of CO_2 to create an accidental release (4).

SECTION 4
HAZARD PREVENTION AND CONTROL

4.1 GENERAL CONSIDERATIONS

The prevention of accidental releases involves a combination of technological, administrative, and operational practices that apply to the design, construction, and operation of facilities where cyanide is stored and used. These areas can be grouped as follows:

- Process design;
- Physical plant design;
- Operating and maintenance; and
- Protective systems.

In each of these areas, specific factors must be considered that could lead to a process upset or equipment failure that could directly cause a release of hydrogen cyanide to the environment. At a minimum, equipment and procedures should be examined to ensure they are in accordance with applicable codes, standards, and regulations. In addition, stricter equipment and procedural specifications should be in place if extra protection against a release is necessary.

The following subsections discuss the specific factors relating to release prevention; more detailed discussions will be found in the manual on control technologies.

4.2 PROCESS DESIGN

The most straightforward method for reducing the potential for an accidental release of hydrogen cyanide from a plating process would be to switch to a non-cyanide-based process, although the plating performance and the economics of operation must be weighed before making such a switch. In most cases, the non-cyanide alternative is more expensive to operate, and the performance of the non-cyanide process may be adequate for only a few applications.

Apart from switching to a non-cyanide process, few possibilities exist for reducing the potential of an accidental release from plating processes because in many respects such processes are static. Because small quantities of liquid cling to the parts as they are transferred between baths, each bath is contaminated; however, this "flow" of liquid between baths is very small. Probably the only other flow of material in a plating process are bath filtering loops. The only control system in a plating operation is likely to be temperature control on some of the baths. Transfers, monitoring and composition adjustments are all done manually.

From a release prevention perspective, pH control of cyanide base plating solutions is very important. In most cases, monitoring and controlling pH control are handled manually. The plating solutions are highly buffered and resistant to pH change. The quality of the plating is usually a good indication of pH variations; a process will not continue to plate properly if the pH falls even slightly.

It would be difficult to automate pH control because pH adjustment can be accomplished by adding several different chemicals. Each situation may require a unique remedy. For example, pH may be low because of cyanide decomposition or because of acid contamination brought in on the surface of the parts being plated. In the first case, the proper remedy may be to adjust the pH by adding sodium cyanide. In the second case, the proper remedy may be

to adjust the pH by adding sodium hydroxide. It would be difficult to design an automatic control system that would make such decisions. Although automatic control may not be practical, the pH could be monitored continuously. Reliable continuous pH monitoring is difficult to achieve; frequent maintenance and recalibration are often required. A continuous monitoring system could incorporate a low pH alarm.

If automatic pH or composition control is incorporated into the plating process, then a backup system, such as an audible low pH alarm or redundant pH sensors and controllers, should be used to help protect the process from control system failures that result in a low cyanide bath pH.

4.3 PHYSICAL PLANT DESIGN

Physical plant design considerations include equipment, siting and layout, and transfer/transport facilities. Vessels, piping and valves, process machinery, instrumentation, and factors such as the location of systems and equipment must all be considered. The following subsections cover various aspects of physical plant design.

4.3.1 Equipment

Materials of Construction --

The primary concern in selecting appropriate materials of construction is preventing major cyanide solution spills and preventing the mixing of acidic materials with cyanide solutions.

Foundations, dikes, walls, flooring and other supports should be fabricated from materials resistant to attack by the chemicals used in the plating process. "Acid brick" combined with chemically resistant mortar is a reliable material to use over a concrete base for protection against corrosion. A concrete base may also be treated with a thermosetting plastic resin coat to provide corrosion resistance.

Polymer concrete is a type of chemically resistant concrete that may be used without a protective coating. Polymer concrete is a mixture of a resinous or sulfur binder with a silica sand filler and graded quartz (silica) aggregate that contain no portland or calcium aluminate, or other hydraulic cement, and no calcium or alumina products. The physical strength of this material is limited and it is prone to shrinkage, however.

Tanks must be constructed of, or lined with, a material resistant to chemical attack. A variety of alternatives are commonly used including lined carbon steel, lined precast or poured-in-place concrete, self-supporting plastic or stainless steel.

A wide variety of tank-lining materials are available. The three basic types are: 1) hot and ambient temperature-applied asphaltics; 2) sheet rubber, plastics, elastomers; and 3) reinforced and nonreinforced ambient-cured synthetic resin systems. Each variety has limitations and applications to which it is best suited. Additional details may be found from vendors and additional texts on the subject (12). Chemical-resistant brick and tile linings, which may be used as a physically protective barrier over a more chemically resistant barrier, such as a lining, are not adequate protection by themselves.

Four basic varieties of plastic tanks are available: 1) polyvinyl chloride, type 1; 2) polypropylene; 3) linear polyethylene; and 4) fabric reinforced plastics. All of these plastics have been successfully used as self-supporting tanks as well as "drop-in" tank liners. As with linings, each variety has limitations and applications for which it is best suited. Further details may be obtained from vendors and texts on the subject (12).

Where cyanide solutions are pumped, carbon steel equipment is satisfactory for velocities less than 1.2 - 1.5 m/sec (4 - 5 ft/sec). At higher velocities, an erosion-corrosion effect occurs and 304 stainless steel must be used. Wetted portions of a pump should be constructed of 304 stainless steel.

Tanks --

Four varieties of tanks are used for cyanide solutions in the plating process; 1) carbon steel; 2) stainless steel; 3) portland cement; and 4) self-supporting plastic. As mentioned previously, carbon steel and cement tanks must be lined.

One widely regarded source of technical information in the plating industry recommends the following fabrication standards for carbon steel and concrete tanks (12).

Carbon steel tanks--

- A minimum number of pieces and sufficient reinforcement must be used to prevent bulging when subjected to maximum process stress.

- Vertical reinforcing is preferred to horizontal. Ledges should be eliminated, thus minimizing potential for drag-out to hang, concentrate and corrode the vessel from the "outside-in".

- Welds to receive lining should be solid and continuous.

- All corners should be ground to a minimum radius of 1/8 inch, with no sharp right angles.

- Exterior reinforcing members may be skip welded.

- All body seams must be butt welded true and flat with variation on alignment not to exceed 25% of plate thickness and in no case more than 1/8 inch.

- All outlets are to be flanged.

- Vessel interiors must be free of weld splatter, pits, deep gouges, and all welds must be ground smooth.

Recommended welding instructions with illustrated details are also included in the text.

Portland cement tanks (12)--

Portland cement concrete tanks are acceptable as long as they:

- Are sufficiently reinforced to prevent buckling and cracking;
- Have a minimum 3,000 PSI compressive strength after 28 days;
- Have a smooth monolithic interior free of ridges, depressions, honeycomb, form marks, etc.;
- Are free of contaminants and additives, i.e., from release agents, air entraining agents, etc.;
- Are hydrostatically tight and waterproofed on the exterior if located below grade.

Self-supporting plastic and stainless steel tanks must comply with structural mandates similar to those enumerated for carbon steel and portland cement concrete.

Piping --

Cyanide solution pipework design must reflect the pressure, temperature, and corrosion concerns associated with use of the chemical. Pipework and fittings in plating operations are not subjected to severe operating

conditions, and their failure would not directly cause a release of hydrogen cyanide. Failure would result in spills of cyanide solutions, however.

Piping systems in a plating process are fairly simple. Care should be taken to segregate and clearly label piping associated with acid cleaning baths and cyanide solutions. Transfer piping and pumps used for acid should be segregated from interaction with piping and pumps used for cyanide solutions. Systems should be designed to prevent backflow of acid into cyanide solutions, and vice versa.

Since equipment is continually in motion overhead as racks of parts are raised and lowered, all pipes and fittings should be protected from overhead collision. Pipes and fittings should also be protected from collision with in-shop vehicles such as fork lifts.

Process Machinery --

Pumps--There are few restrictions on the type of pump for cyanide plating solutions.

Wetted parts should be made of 304 stainless steel (4). Mechanical seals are preferred over packing for better leak protection. Pumps handling cyanide solutions should be located within a curbed or diked area. The pump should be located within an area of controlled ventilation.

Instrumentation--pH monitoring is the most important instrumentation item associated with accidental release prevention. Continuous monitoring with a low pH alarm is preferred.

4.3.2 Plant Siting and Layout

The siting and layout of a plating facility that uses cyanide requires careful consideration of numerous factors, including: other processes in the

area, the proximity of population centers, prevailing winds, local terrain, and potential natural external effects such as flooding. This subsection describes general considerations that might apply to the siting and layout of plating facilities.

Facilities should be laid out and individual equipment items should be placed to reduce personnel exposure in the event of a release. Since there are also other siting considerations, there may be trade-offs between this requirement and others in a process, some directly related to safety. There must be ready ingress or egress in the event of an emergency. Siting should also take advantage of barriers, either man-made or natural, which could reduce the consequences of releases.

Layout refers to the placement and arrangement of equipment in the process facility. General layout considerations include:

- Stored inventories of solid cyanide salts should be separated from inventories of acid. Support dikes or curbs should be around acid storage tanks and cyanide salt storage areas to ensure that any spilled acid cannot reach the dry salts.

- Cyanide salts should be protected from contact with moisture. If wetted, the runoff should be contained and routed to treatment and disposal facilities.

- Adequate drainage or diking should be available to prevent runoff or spills in the plating process from leaving the plating building.

- Cyanide solutions should not be stored in a sealed container without pressure relief, because slow hydrolytic decomposition can result in the formation of ammonia.

Over time, the ammonia level can lead to a significant increase in pressure.

- An overflow or leak from one bath must not contaminate another bath.

- Sodium or other solid cyanide storage areas and the plating process itself should be protected from collision with vehicle traffic.

4.4 PROTECTION TECHNOLOGIES

This subsection describes two protection technologies for containing and neutralizing a released chemical:

- Enclosures; and

- Scrubbers.

4.4.1 Enclosures

Enclosures are buildings and ventilation systems used to capture and temporarily contain hydrogen cyanide vapors until they can be disposed of without threatening the nearby environment or personnel. The first enclosure option provides the entire building with adequate ventilation to remove hydrogen cyanide vapors as they are formed. The second includes individual hoods that capture vapors from areas where hydrogen cyanide might be generated. Some combination of these two is often employed.

Capture hoods must be located to the side of, or high enough above the plating baths to allow racks to be loaded into and out of the baths. Hoods and building ventilation systems already found in some facilities are primarily used for plant personnel protection against small quantities of hydrogen cyanide or other fumes that might be released from the plating tanks.

Special hoods and ventilation systems for large cyanide releases may require different designs than standard hood ventilation systems. The discharge from these systems could be routed to a scrubber.

4.4.2 Scrubbers

Scrubbers, a traditional method for absorbing toxic gases from process streams, can be used for controlling hydrogen cyanide releases collected in hood and ventilation systems.

Hydrogen cyanide discharges can be contacted with an aqueous scrubbing medium in any of several types of scrubbing devices. An alkaline solution may be required to achieve effective absorption because absorption rates with water alone might require unreasonably high liquid-to-gas ratios.

Types of scrubbers that might be appropriate include spray towers, packed bed scrubbers, and venturis. Other types of special designs might be suitable, but no matter what type of scrubber is selected, a complete system will include the scrubber itself, a liquid feed system, and reagent makeup equipment. If such a system is used to protect against accidental releases, it is necessary to know how it would be activated in time to respond to an emergency load. One approach used in some process facilities is to maintain a continuous circulation of scrubbing liquor through the system. For many facilities this would not be practical; the scrubber system might be tied into a trip system to turn it on when it is needed. Another approach is to route the vent to the bottom of a large tank of uncirculating caustic, but this technique does not have the high contact efficiency of the other scrubber types. However, it can provide substantial capacity on demand as long as the back pressure of the hydrostatic head does not create a secondary hazard, by impeding a discharge, for example. A larger than normal ventilation blower may be required to blow air containing toxic vapor through the solution tank.

Venturi scrubbers have an advantage when the scrubbing system must be activated by a trip system. A venturi scrubber can create its own draw of vapor by the flow of the liquid. Thus a trip system need only turn on the flow of liquid to the scrubber, rather than turn on the flow of liquid and start up a blower, as would be required in other types.

It would appear that for most cyanide plating operations, scrubber systems may be a level of protection out of proportion to the hazard, but they could be used where extreme precautions are required.

4.5 MITIGATION TECHNOLOGIES

If, in spite of all precautions, a release of hydrogen cyanide occurs, the first priority is to rescue workers in the immediate vicinity of the accident and evacuate persons from downwind areas. The source of the release should be determined, and the leak should be plugged to stop the flow if this is possible. The next primary concern becomes reducing the consequences of the released chemical to the plant and the surrounding community, referred to as mitigation. Mitigation technologies include such measures as physical barriers, water sprays and fogs, and foams where applicable. The purpose of a mitigation technique is to direct, limit, or disperse the chemical that has been spilled or released to the atmosphere to reduce the atmospheric concentration and the area affected by the chemical. The mitigation technology chosen for a particular chemical depends on the specific properties of the chemical, including its flammability, toxicity, reactivity, and those properties that determine its dispersion characteristics in the atmosphere. In addition, secondary containment systems (such as diking) are used to contain accidental liquid spills and to reduce the rate of evaporation by minimizing the surface area of the spilled liquid.

The availability of proper personnel protection is also important in the event of an accident. Such protection will include the availability of air and chemically resistant clothing.

4.5.1 Secondary Containment Systems

Diking is a form of partial secondary containment that provides a liquid-retaining barrier around the perimeter of process or storage areas. Usually, such diking is designed to retain the full volume of a liquid that might potentially be spilled within the diked area. Because the diking encloses a ground area considerably larger than the equipment it protects, the height of the diking does not usually extend beyond the height of the protected equipment. Piping should be routed over dike walls, and penetrations through the walls should be avoided if possible.

A dike can effectively contain the liquid portion of an accidental release and keep the liquid from entering uncontrolled areas. By preventing the liquid from spreading, the dike reduces the surface area of the spill, which in turn reduces the rate of evaporation. For outdoor operations, the dike will partially protect the spill from wind, which can also reduce the rate of evaporation.

In a plating operation, diking should be considered for baths containing cyanide solutions. Care should be taken to avoid mixing the acid bath and cyanide bath contents in the event that both are emptied into the diked area.

Additionally, separate diking or curbing should be placed around acid storage tanks and cyanide salt storage areas to ensure that any spilled acid is contained and cannot reach dry cyanide storage areas.

4.5.2 Foam Systems

If an accidental release of hydrogen cyanide would result in hazardous conditions in surrounding communities, a foam system could be used to control the hazard. The use of a foam layer in vapor hazard control has been demonstrated for a broad range of volatile chemicals (13). Unfortunately, it is difficult to accurately quantify the benefits of foam systems, because the

effects will vary according to the chemical spilled, the foam type, the spill size, and atmospheric conditions.

When a foam layer is first applied to the source of hydrogen cyanide, a short-term increase in the downwind hydrogen cyanide concentration may be observed. Once a continuous layer is formed over the hydrogen cyanide source, however, the downwind concentration will decrease as a result of increased chemical dilution with air, of a reduced vaporization rate, and of the increased buoyancy of the vapor cloud. This latter effect is a result of the vapor being warmed as it rises through the blanket by heat transfer from the foam and by the heat of solution of hydrogen cyanide in water; the warmed vapor cloud will have greater buoyancy and will disperse in an upward direction more rapidly.

The extent of the downwind concentration reduction will depend on the type of foam used. Research in this area has indicated that for some chemicals, medium to high expansion foams (300 to 350:1) give significantly better results than do low expansion foams (6 to 8:1), while for others the opposite may be true (13,14).

Regardless of the type of foam used, the slower the drainage rate of the foam, the better its performance will be. A slow-draining foam will spread more evenly, show more resistance to temperature and pH effects, and collapse more slowly. A slow draining foam may be more expensive than other foams, but the superior performance makes it cost effective.

Since the potential for a large HCN release will probably be very low for most plating operations, the cost of a foam system must be weighed against the potential for such a release.

4.6 OPERATION AND MAINTENANCE PRACTICES

Accidental air releases of toxic chemicals result not only from deficiencies of design but also from deficiencies of operation. Thus safe operation of plating plants using cyanide requires competent and experienced supervisors and staff in addition to a well-considered and fully understood system of work.

Employees should be thoroughly educated about the important aspects of handling cyanide salts and cyanide solutions, including: the proper means of handling and storing, hazards resulting from improper use and handling, prevention of spills, cleanup procedures, maintenance procedures and emergency procedures. Well-defined procedures can decrease the possibility of a hazardous release and can also reduce the magnitude of an accidental release.

4.7 CONTROL EFFECTIVENESS

It is difficult to quantify the control effectiveness of preventive and protective measures. Preventive measures, which may involve numerous combinations of process design, equipment design, and operation measures, are especially difficult to quantify because they reduce a probability rather than a physical quantity of a chemical release. Because protective measures are more analogous to traditional pollution control technologies, they may be easier to quantify in terms of their efficiency in reducing the quantity of released chemical.

Preventive measures reduce the probability of an accidental release by increasing the reliability of both the process systems operations and of the equipment. Control effectiveness can thus be expressed for both the qualitative and the quantitative improvements through probabilities. Table 4-1 summarizes what appear to be some of the major design, equipment, and operational measures applicable to the primary hazards identified for hydrogen cyanide applications in the SCAQMD.

TABLE 4-1. EXAMPLES OF MAJOR PREVENTION AND PROTECTION MEASURES FOR HYDROGEN CYANIDE RELEASES

Hazard Area	Prevention/Protection
Fire in Process Area	Sprinkler systems Segregation of cyanide salts from acids in storage areas Diking or other drainage control around -- cyanide storage -- plating baths -- entire plating shop
Line, pipe, or valve failure	Use 304 stainless steel construction Use flanged or butt-weld construction Locate piping within a diked area Inspect regularly
Tank Overfill	Arrange adjacent tanks so that an overfill from one tank does not contaminate another tank Enclose cyanide solutions in a separate diked area away from acid solutions
Accidental Transfer of cyanide solution to acid tank or acid tank to cyanide solution	Segregate acid handling lines from cyanide solution handling lines Clearly label all lines Improve operator training
Cyanide bath failure	Surround bath with diking Use recognized design procedures for bath construction Use materials of construction that are suitable for cyanide service Inspect regularly for corrosion Protect bath from damage by vehicle collision
Overcharge of acid to cyanide bath	Improve operator training

4.8 ILLUSTRATIVE COST ESTIMATES FOR CONTROLS

This section presents cost estimates for different levels of control and for specific release prevention and protection measures that might be found in the SCAQMD for hydrogen cyanide containing process facilities.

4.8.1 Levels of Control

The prevention of accidental releases relies on a combination of technological, administrative, and operational practices as they apply to the design, construction, and operation of facilities where hazardous chemicals are used and stored. At a minimum, equipment and procedures should be in accordance with applicable codes, standards, and regulations; however, additional measures can be taken to provide extra protection against an accidental release.

The levels of control concept provides a means of assigning costs to increased levels of prevention and protection. The minimum level is referred to as the "Baseline" system. This system consists of the elements required for normal safe operation and basic prevention of an accidental release of hazardous material.

The second level of control is "Level 1". "Level 1" includes the baseline system with added modifications, such as improved materials of construction, additional controls, and generally more extensive release prevention measures. The costs associated with this level are higher than the baseline system costs.

The third level of control is "Level 2". This system incorporates both the "Baseline" and "Level 1" systems with additional modifications designed specifically for the prevention of an accidental release, such as alarm and interlock systems. The extra accidental release prevention measures

incorporated into "Level 2" are reflected in its cost, which is much higher than that of the baseline system.

When comparing the costs of the various levels of control, it is important to realize that higher costs do not necessarily imply improved safety. The measures applied must be applied correctly. Inappropriate modifications or add-ons may not make a system safer. Each added control option increases the complexity of a system. In some cases the hazards associated with the increased complexity may outweigh the benefits derived from the particular control option. Proper design and construction along with proper operational practices are needed to assure safe operation.

These estimates are for illustrative purposes only. It is doubtful that any specific installation would find all of the control options listed in these tables appropriate. An actual system is likely to incorporate some items from each of the levels of control and also some control options not listed here. The purpose of these estimates is to illustrate the relationship between cost and control, not to provide an equipment check list.

Levels of control cost estimates were prepared for copper-cyanide plating bath system with a capacity of 2,000 gal. This system is representative of a process facility that might be found in the SCAQMD.

4.8.2 Cost Summaries

Table 4-2 summarizes the total capital and annual costs for each of the three levels of controls for the cyanide-copper plating bath system. The costs presented correspond to the system described in Table 4-3. Each of the level costs includes the cost of the basic system plus any added controls. Specific cost information and a breakdown for each level of control for the process facility are presented in Tables 4-4 through 4-6.

TABLE 4-2. SUMMARY COST ESTIMATES OF POTENTIAL LEVELS OF CONTROLS FOR COPPER-CYANIDE PLATING BATH SYSTEM

System	Level of Control	Total Capital Cost (1986 $)	Total Annual Cost (1986 $/yr)
Copper-Cyanide Plating Bath System, with a 2,000 gal Plating Bath	Baseline	119,000	15,000
	Level #1	237,000	29,000
	Level #2	282,000	34,000

TABLE 4-3. EXAMPLE OF LEVELS OF CONTROL FOR COPPER-CYANIDE PLATING BATH SYSTEM

Controls	Baseline	Level #1	Level #2
Process:	None.	None.	Switch to alternative bath solution.
Temperature:	Local temperature indicator.	Add temperature alarm and redundant sensors.	Same.
Pressure:	None.	None.	None.
Flow:	None.	None.	None.
Quantity:	None.	None.	None.
Composition:	Manual pH monitoring and control.	Add automatic pH monitoring system	Add pH alarm.
Mixing:	Provide adequate mixing.	Same.	Same.
Material of Construction:	Fiber-reinforced plastic	Same.	Same.
Piping:	Sch. 40 CPVC.	Sch. 80 CPVC.	Sch. 80 CPVC.
Enclosures:	Building with adequate ventilation for small quantities of HCN.	Add fume hoods over tanks.	Size system for large release of HCN.
Scrubbers:	None.	Water scrubber.	Alkaline scrubber.
Diking:	None.	Around acid storage tanks.	Same.
Location:	Such that acid and stored cyanide are isolated.	Same.	Same.

TABLE 4-4. CAPITAL AND ANNUAL COSTS ASSOCIATED WITH BASELINE COPPER-CYANIDE PLATING BATH SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Equipment:		
Plating tank system		
Tank		
Electric system		
Cooling/heating system		
Total equipment cost	105,000	13,000
Piping and Valves:		
Pipework	510	60
Ball valves (2)	280	35
Instrumentation:		
Temperature indicator	2,200	260
Enclosure:		
Steel building	11,000	1,300
Procedures and Practices:		
Visual tank inspection (external)		10
Visual tank inspection (internal)		15
Piping and valve inspection		20
Total Costs	119,000	15,000

TABLE 4-5. CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 1 COPPER-CYANIDE PLATING BATH SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Equipment:		
Plating tank system		
Tank		
Electric system		
Cooling/heating system		
Total equipment cost	105,000	13,000
Piping and Valves:		
Pipework	690	90
Ball valves (2)	280	35
Instrumentation:		
Temperature indicator	2,200	260
Temperature sensor	360	45
Temperature alarm	360	45
pH monitoring system	9,000	1,100
Enclosure:		
Steel building	11,000	1,500
Capture Hood	3,200	380
Scrubber:		
Water scrubber	105,000	13,000
Diking:		
3 ft. high diking	330	40

(Continued)

TABLE 4-5 (Continued)

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Procedures and Practices:		
Visual tank inspection (external)		10
Visual tank inspection (internal)		15
Piping and valve inspection		20
Total Costs	237,000	29,000

TABLE 4-6. CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 2 COPPER-CYANIDE PLATING BATH SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Equipment:		
Plating tank system		
Tank		
Electric system		
Cooling/heating system		
Total equipment cost	105,000	13,000
Piping and Valves:		
Pipework	690	90
Ball valves (2)	280	35
Instrumentation:		
Temperature indicator	2,200	260
Temperature sensor	360	45
Temperature alarm	360	45
pH monitoring system	9,000	1,100
pH alarm	550	65
Enclosure:		
Steel building	12,000	1,500
Capture Hood	4,200	500
Scrubber:		
Alkaline scrubber	147,000	18,000

(Continued)

TABLE 4-6 (Continued)

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Diking:		
3 ft. high diking	330	40
Procedures and Practices:		
Visual tank inspection (external)		10
Visual tank inspection (internal)		15
Piping and valve inspection		20
Total Costs	282,000	34,000

4.8.3 Equipment Specifications and Detailed Costs

Equipment specifications and details of the capital cost estimates for the copper-cyanide plating bath system are presented in Tables 4-7 through 4-10.

4.8.4 Methodology

Format for Presenting Cost Estimates--

Tables are provided for control schemes associated with a process facility containing hydrogen cyanide. These tables include capital, operating, and total annual costs. The tables are broken down into subsections comprising vessels, piping and valves, process machinery, instrumentation, and procedures and practice. Presentation of the costs in this manner allows for easy comparison of specific items, different levels, and different systems.

Capital Cost--All capital costs presented in this report are shown as total fixed capital costs. Table 4-11 defines the cost elements comprising total fixed capital as it is used here.

The computation of total fixed capital, as shown in Table 4-11, begins with the total direct cost for the system under consideration. This total direct cost is the total direct installed cost of all capital equipment comprising the system. Depending on the specific equipment item involved, the direct capital cost was available or was derived from uninstalled equipment costs by computing costs of installation separately. To obtain the total fixed capital cost, other costs obtained by using factors are added to the total direct costs.

The first group of other cost elements is indirect costs. These include engineering and supervision, construction expenses, and various other expenses such as administration expenses. These costs are computed by multiplying total direct costs by a factor shown in Table 4-11. The factor is

TABLE 4-7. EQUIPMENT SPECIFICATIONS FOR COPPER-CYANIDE PLATING BATH SYSTEM

Equipment Item	Equipment Specification	Reference
Plating bath system	3ft. x 14 ft. x 7 ft. fiber-reinforced plastic	15
Piping and Valves:		
Pipework	Baseline: Schedule 40 CPVC, 25 ft. Schedule 80 CPVC, 25 ft.	16,17
Ball valves	CPVC, Teflon seats	17,18
Instrumentation:		
Temperature indicator	Thermocouple, thermowell, and electronic indicator	17,18,19
Temp. sensor	Thermocouple and associated thermowell	17,19
Temp. alarm	Indicating and audible alarm	17,20,21
pH monitoring system	Electrode, electrode chamber, amplifier-transmitter, indicator	18,22
pH alarm	Indicating and audible alarm	17,20,21
Enclosure:	Baseline: steel building with limited ventilation system Level 1: Steel building with hoods over bath, limited ventilation Level 2: Steel building with hood over bath, maximum ventilation	20,23
Scrubber:	Level 1: spray tower, water sprays, SS type 304 construction Level 2: spray tower, alkaline sprays, SS type 304 construction	24
Diking:	3 ft. high diking around acid storage area	20

TABLE 4-8. MATERIAL AND LABOR COSTS ASSOCIATED WITH BASELINE COPPER-CYANIDE PLATING BATH SYSTEM

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Equipment:					
Plating Tank System					
Tank					
Electrical system					
Cooling/heating system					
Total Equip. Cost	50,000	23,000	73,000	18,000	105,000
Piping and Valves:					
Pipework	200	150	350	90	510
Ball valves (2)	150	40	190	50	280
Instrumentation:					
Temperature indicator	1,200	300	1,500	380	2,200
Enclosure:					
Steel building	5,000	2,500	7,500	1,900	11,000
Total Costs	57,000	26,000	83,000	20,000	119,000

TABLE 4-9. MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 1 COPPER-CYANIDE PLATING BATH SYSTEM

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Equipment:					
Plating Tank System					
Tank					
Electrical system					
Cooling/heating system					
Total Equip. Cost	50,000	23,000	73,000	18,000	105,000
Piping and Valves:					
Pipework	300	180	480	120	690
Ball valves (2)	150	40	190	50	280
Instrumentation:					
Temperature indicator	1,200	300	1,500	380	2,200
Temperature sensor	200	50	250	60	360
Temperature alarm	200	50	250	60	360
pH monitoring system	5,000	1,300	6,300	1,600	9,000

(Continued)

TABLE 4-9 (Continued)

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Enclosure:					
Steel building	5,000	2,500	7,500	1,900	11,000
Capture hood	1,500	680	2,180	550	3,200
Scrubber:					
Water scrubber	50,000	23,000	73,000	18,000	105,000
Diking:					
3 ft. high diking	100	130	230	60	330
Total Costs	114,000	50,000	164,000	41,000	237,000

TABLE 4-10. MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 2 COPPER-CYANIDE PLATING BATH SYSTEM

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Equipment:					
Plating Tank System					
Tank					
Electrical system					
Cooling/heating system					
Total Equip. Cost	50,000	23,000	73,000	18,000	105,000
Piping and Valves:					
Pipework	300	180	480	120	690
Ball valves (2)	150	40	190	50	280
Instrumentation:					
Temperature indicator	1,200	300	1,500	380	2,200
Temperature sensor	200	50	250	60	360
Temperature alarm	200	50	250	60	360
pH monitoring system	5,000	1,300	6,300	1,600	9,000
pH alarm	300	75	375	100	550

(Continued)

TABLE 4-10 (Continued)

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Enclosure:					
Steel building	6,000	2,500	8,500	2,100	12,000
Capture hood	2,000	900	2,900	730	4,200
Scrubber:					
Alkaline scrubber	70,000	32,000	102,000	26,000	147,000
Diking:					
3 ft. high diking	100	130	230	60	330
Total Costs	136,000	60,000	196,000	49,000	282,000

TABLE 4-11. FORMAT FOR TOTAL FIXED CAPITAL COST

Item No.	Item	Cost
1	Total Material Cost	-
2	Total Labor Cost	-
3	Total Direct Cost	Items 1 + 2
4	Indirect Cost Items (Engineering & Construction Expenses)	0.35 x Item 3[a]
5	Total Bare Module Cost	Items (3 + 4)
6	Contingency	(0.05 x Item 5)[b]
7	Contractor's Fee	0.05 x Item 5
8	Total Fixed Capital Cost	Items (5 + 6 + 7)

[a]For storage facilities, the indirect cost factor is 0.35. For process facilities, the indirect cost factor is 0.25.

[b]For storage facilities, the contingency cost factor is 0.05. For process facilities, the contingency cost factor is 0.10.

approximate, is obtained from the cost literature, and is based on previous experience with capital projects of a similar nature. Factors can have a range of values and vary according to technology area and for individual technologies within an area. Appropriate factors based on judgement and experience were selected for this report.

When the indirect costs are added to the total direct costs, total bare module cost is obtained. Some additional cost elements, such as contractor's fee and contingency, are calculated by applying and adding appropriate factors to the total bare module cost, as shown in Table 4-11, to obtain the total fixed capital cost.

Annual Cost--Annual costs are obtained for each equipment item by applying a factor for both capital recovery and for maintenance expenses to the direct cost of each equipment item. Table 4-12 defines the cost elements and the appropriate factors comprising these costs. Additional annual costs are incurred for procedural items such as valve and vessel inspections, for example. The sum of these individual costs equals the total annual cost.

Sources of Information--

Costs presented in this report are derived from cost information in existing published sources and also from recent vendor information. The objective of this effort was to present cost levels for a hydrogen cyanide-containing process facility using the best costs for available sources. The primary sources of cost information are Peters and Timmerhaus (18), Chemical Engineering (25), and Valle-Riestra (26) supplemented by other sources and references where necessary. Adjustments were made to update all costs to a June 1986 dollar basis. For some equipment items, well-documented costs were not available and they had to be developed from component costs.

Costs in this document reflect the "typical" or "average" representation for specific equipment items. This restricts the use of data in this report to:

TABLE 4-12. FORMAT FOR TOTAL ANNUAL COST

Item No.	Item	Cost
1	Total Direct Cost	-
2	Capital Recovery on Equipment Items	0.163 x Item 1
3	Maintenance Expense on Equipment Items	0.01 x Item 1
4	Total Procedural Items	-
5	Total Annual Cost	Items (2 + 3 + 4)

- Preliminary estimates used for policy planning;
- Comparison of relative costs of different levels or systems; and
- Approximations of costs that might be incurred for a specific application.

The costs in this report are considered to be "order of magnitude" with a ±50 percent margin. This is because costs are based on preliminary estimates and many are updated from literature sources. Large departures from the design basis of a particular system presented in this manual or the advent of a different technology might cause the system cost to vary more than this. If used as intended, however, this document will provide a reasonable source of preliminary cost information for the facilities covered.

When comparing costs in this manual to those from other references, the user should be sure the design bases are comparable and that the capital and annual costs as defined here are the same.

Cost Updating--

All costs in this report are expressed in June 1986 dollars. Costs reported in the literature were updated using cost indices for materials and labor.

Costs expressed in base-year dollars may be adjusted to dollars for another year by applying cost indices as shown in the following equation:

$$\text{new base-year cost} = \text{old base-year cost} \times \frac{\text{new base year index}}{\text{old base year index}}$$

The Chemical Engineering (CE) Plant Cost Index was used to update costs for this report. For June 1986, the index is 316.3.

Equipment Costs--

Most of the equipment costs presented in this manual were obtained directly from literature sources of vendor information and correspond to a specific design standard. Special cost estimating techniques, however, were used in determining the costs associated with vessels, piping systems, scrubbers, diking, and enclosures. The techniques used are presented in the following subsections of this manual.

Vessels--The total purchased cost for a vessel, as dollars per pound of weight of fabricated unit f.o.b. (free on board), with carbon steel as the basis (January 1979 dollars) were determined using the following equation from Peters and Timmerhaus (18):

$$\text{Cost} = [50(\text{Weight of Vessel in Pounds})^{-0.34}][\text{Weight of Vessel in Pounds}]$$

The vessel weight is determined using appropriate design equations, as given by Peters and Timmerhaus (18), that allow for wall thickness adjustments for corrosion allowances, for example. The vessel weight is increased by a factor of 0.15 for horizontal vessels and 0.20 for vertical vessels to account for the added weight of nozzles, manholes, and skirts or saddles. Appropriate factors are applied for different materials of construction as given in Peters and Timmerhaus (18). Vessel costs are updated using cost factors. Finally a shipping cost amounting to 10 percent of the purchased cost is added to obtain the delivered equipment cost.

Piping--Piping costs were obtained using cost information and data presented by Yamartino (16). A simplified approach is used in which it is assumed that a certain length of piping containing a given number of valves, flanges, and fittings is contained in the storage or process facility. The data presented by Yamartino (16) permit cost determinations for various lengths, sizes, and types of piping systems. Using these factors, a representative estimate can be obtained for each of the storage and process facilities.

Diking--Diking costs were estimated using Mean's Manual (20) for reinforced concrete walls. The following assumptions were made to determine the costs. The dike contains the entire contents of a tank in the event of a leak or release. Two dike sizes are possible: a three-foot high dike, six-inches thick and a top-of-tank height dike ten inches thick. The tanks are raised off the ground and are not volumetrically included in the volume enclosed by the diking. These assumptions facilitate cost determination for any size diking system.

Enclosures and Capture Hoods--Enclosure costs were estimated using Mean's Manual (20) for both reinforced concrete and steel-walled buildings. The buildings are assumed to enclose the same area and volume as the top-of-tank height dikes. The concrete building is ten-inches thick with a 26-gauge steel roof and a metal door. The steel building has 26 gauge roofing and siding and a metal door. The cost of a ventilation system was determined using a typical 1,000 scfm unit and doubling the cost to account for duct work and requirements for the safe enclosure of hazardous chemicals. The cost for a capture hood was determined using a graphical technique developed by Vatavuk and Neveril (20) for pollutant capture hoods.

Scrubbers--Scrubber costs were estimated using the following equation from the Gard (21) manual for spray towers based on the actual cubic feet per minute of flow at a chamber velocity of 600 feet/minute.

$$\text{Costs} = 0.235 \times (\text{ACFM} + 43{,}000)$$

A release rate of 100 ft^3/minute was assumed for the copper-cyanide plating bath system based on the possible quantity of hazardous chemical present. In addition to the spray tower, the costs also include pumps and a storage tank for the scrubbing medium. The costs presented are updated to June 1986 dollars.

Installation Factors--

Installation costs were developed for all equipment items included in the process system. The costs include both the material and labor costs for installation of a particular piece of equipment. The costs were obtained directly from literature sources and vendor information or indirectly by assuming a certain percentage of the purchased equipment cost through the use of estimating factors obtained from Peters and Timmerhaus (18) and Valle-Riestra (26). Table 4-13 lists the cost factors used or the reference from which the cost was obtained directly. Many of the costs obtained from the literature were updated to June 1986 dollars using a 10 percent per year rate of increase for labor and cost indices for materials associated with installation.

TABLE 4-13. FORMAT FOR INSTALLATION COSTS

Equipment Item	Factor or Reference
Vessels:	
Plating Bath System	0.45
Piping and Valves:	
Pipework	Ref. 13
Ball Valves	Ref. 14
Instrumentation:	
All Instrumentation Items	0.25
Enclosures:	Ref. 17 and 20
Diking:	Ref. 17
Scrubber:	0.45

SECTION 5
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APPENDIX A
GLOSSARY

This glossary defines selected terms used in the text of this manual which might be unfamiliar to some users or which might be used differently by different authors.

Accidental release: The unintentional spilling, leaking, pumping, purging, emitting, emptying, discharging, escaping, dumping, or disposing of a toxic material into the environment in a manner that is not in compliance with a plant's federal, state, or local environmental permits and/or results in toxic concentrations in the air that are a potential health threat to the surrounding community.

Assessment: The process whereby the hazards which have been identified are evaluated in order to provide an estimate for the level of risk.

Containment/control: A system to which toxic emissions from safety relief discharges are routed to be controlled. A caustic scrubber and/or flare can be containment/control devices. These systems may serve the dual function of destructing continuous process exhaust gas emissions.

Facility: A location at which a process or set of processes are used to produce, refine or repackage chemicals, or a location where a large enough inventory of chemicals are stored so that a significant accidental release of a toxic chemical is possible.

Hazard: A source of danger. The potential for death, injury or other forms of damage to life and property.

Identification: The recognition of a situation, its causes and consequences relating to a defined potential, e.g. Hazard Identification.

Mild steel: Carbon steel containing a maximum of about 0.25% carbon. Mild steel is satisfactory for use where severe corrodants are not encountered or where protective coatings can be used to prevent or reduce corrosion rates to acceptable levels.

Mitigation: Any measure taken to reduce the severity of the adverse effects associated with the accidental release of a hazardous chemical.

Passivation film: A layer of oxide or other chemical compound of a metal on its surface that acts as a protective barrier against corrosion or further chemical reaction.

Plant: A location at which a process or set of processes are used to produce, refine, or repackage, chemicals.

Prevention: Design and operating measures applied to a process to ensure that primary containment of toxic chemicals is maintained. Primary containment means confinement of toxic chemicals within the equipment intended for normal operating conditions.

Primary Containment: The containment provided by the piping, vessels and machinery used in a facility for handling chemicals under normal operating conditions.

Probability/potential: A measure, either qualitative or quantitative, that an event will occur within some unit of time.

Process: The sequence of physical and chemical operations for the production, refining, repackaging or storage of chemicals.

Process machinery: Process equipment, such as pumps, compressors, heaters, or agitators, that would not be categorized as piping or vessels.

Protection: Measures taken to capture or destroy a toxic chemical that has breached primary containment, but before an uncontrolled release to the environment has occurred.

Qualitative Evaluation: Assessing the risk of an accidental release at a facility in relative terms; the end result of the assessment being a verbal description of the risk.

Quantitative Evaluation: Assessing the risk of an accidental release at a facility in numerical terms; the end result of the assessment being some type of number reflects risk, such as faults per year or mean time between failure.

Reactivity: The ability of one chemical to undergo a chemical reaction with another chemical. Reactivity of one chemical is always measured in reference to the potential for reaction with itself or with another chemical. A chemical is sometimes said to be "reactive", or have high "reactivity", without reference to another chemical. Usually this means that the chemical has the ability to react with common materials such as water, or common materials of construction such as carbon steel.

Redundancy: For control systems, redundancy is the presence of a second piece of control equipment where only one would be required. The second piece of equipment is installed to act as a backup in the event that the primary piece of equipment fails. Redundant equipment can be installed to backup all or selected portions of a control system.

Risk: The probability that a hazard may be realized at any specified level in a given span of time.

Secondary Containment: Process equipment specifically designed to contain material that has breached primary containment before the material is released to the environment and becomes an accidental release. A vent duct and scrubber that are attached to the outlet of a pressure relief device are examples of secondary containment.

Toxicity: A measure of the adverse health effects of exposure to a chemical.

APPENDIX B

TABLE B-1. METRIC (SI) CONVERSION FACTORS

Quantity	To Convert From	To	Multiply By
Length:	in	cm	2.54
	ft	m	0.3048
Area:	in^2	cm^2	6.4516
	ft^2	m^2	0.0929
Volume:	in^3	cm^3	16.39
	ft^3	m^3	0.0283
	gal	m^3	0.0038
Mass (weight):	lb	kg	0.4536
	short ton (ton)	Mg	0.9072
	short ton (ton)	metric ton (t)	0.9072
Pressure:	atm	kPa	101.3
	mm Hg	kPa	0.133
	psia	kPa	6.895
	psig	kPa*	((psig)+14.696)x(6.895)
Temperature:	°F	°C*	(5/9)x(°F-32)
	°C	K*	°C+273.15
Caloric Value;	Btu/lb	kJ/kg	2.326
Enthalpy:	Btu/lbmol	kJ/kgmol	2.326
	kcal/gmol	kJ/kgmol	4.184
Specific-Heat Capacity:	Btu/lb-°F	kJ/kg-°C	4.1868
Density:	lb/ft^3	kg/m^3	16.02
	lb/gal	kg/m^3	119.8
Concentration:	oz/gal	kg/m^3	
	quarts/gal	cm^3/m^3	25,000
Flowrate:	gal/min	m^3/min	0.0038
	gal/day	m^3/day	0.0038
	ft^3/min	m^3/min	0.0283
Velocity:	ft/min	m/min	0.3048
	ft/sec	m/sec	0.3048
Viscosity:	centipoise (CP)	Pa-s (kg/m-s)	0.001

*Calculate as indicated